FEDERAL UNIVERSITY OF SÃO PAULO

DEPARTMENT OF SCIENCE AND TECHNOLOGY

PROFESSIONAL MASTER'S PROGRAM IN TECHNOLOGICAL INNOVATION

EVALUATION OF THE LORAWAN WIRELESS COMMUNICATION PROTOCOL AND ITS APPLICABILITY IN MONITORING CLIMATE CONDITIONS

Lucas Restivo de Oliveira

Supervisor: Prof. Dr. Arlindo Flavio da Conceição
Co-Supervisor: Prof. Dr. Lauro Paulo da Silva Neto

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Dissertation presented to the Professional Master's Program in Technological Innovation of the Federal University of São Paulo, as part of the requirements to obtain the title of Master in Science
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I dedicate this work to my parents, Kelli and Eduardo, who have always motivated me to seek opportunities for knowledge, my brothers, Mateus, Pedro and Maria Eduarda, for the affection and support, to all my friends and family that have been part of my journey in this study, and to my supervisor Dr. Arlindo, for the opportunity, attention and patience.

There are no two words more harmful than good job.

J.K. Simmons, Whiplash

Abstract

This work aimed to understand the methodology of implementation of the Internet of Things in Brazil through LoRa technology, which in recent years has shown enormous applicability for remote sensing in several countries around the world. The main characteristics of this type of long distance transmission, such as payload of up to 242 B, transmission rate of 27 kbps, range of up to 30 km, battery life of up to 10 years, node sensitivity of -136 dBm, bandwidth up to 500 kHz and operation in frequency-free spectrum (also known as Industrial Scientific and Medical, or, ISM), are directed to identify that there is an applicability of LoRa in the prevention of natural disasters, urban waste management and productivity in industries or rural areas. Thus, the main focus of this work was to provide a practical contribution to accessible and low cost hardware for the use of LoRa technology in Brazil, prototyping tests of reach, energy efficiency and technical feasibility for the national operation. It was possible to create a reusable programming library (LoBRa) for the hardware used that meets the transmission constraints in accordance with the regulations of the regulatory bodies.

Keywords: LoRa, LoRaWAN, IoT, monitoring

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List of Acronyms

A	Ampere
ACM	Association for Computing Machinery
ADR	Adaptive Data Rate
AES	Advanced Encryption Standard
Anatel	National Telecommunications Agency
ARM	Advanced RISC Machine
b	Bits
B	Bytes
BID	Inter-American Development Bank
BLE	Bluetooth Low Energy
Cemaden	National Center for Natural Disaster Monitoring and Alerts
Cenad	National Center for Risk and Disaster Management
CPS	Cyber-Physical System
CR	Coding Rate
CSS	Chirp Spread Spectrum
dB	Decibel
dBm	Decibel miliwatt
DCP	Data Collection Platform
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FIFO	First In First Out
FSK	Frequency Shift Keying
FTDI	Future Technology Devices International
FTP	File Transfer Protocol
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum-Shift Keying
GPRS	General Packet Radio Services

GSM	Global System for Mobile Communications
HDMI	High-Definition Multimedia Interface
Hz	Hertz
ICMP	Internet Control Message Protocol
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISM	Industrial, Scientific & Medical
ITU	International Telecommunication Union
LAN	Local Area Network
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
LTE	Long-Term Evolution
m	Meter
MDT	Digital Terrain Models
MQTT	Message Queuing Telemetry Transport
MSK	Minimum Shift Keying
NTP	Network Time Protocol
OOK	On-Off Keying
OSI	Open System Interconnection
PCB	Printed Circuit Boards
PNMS	DCP Network Management System
RF	Radio Frequency
RPi	Raspberry Pi
RSSI	Received Signal Strength Indicator
RTS	Robotized Total Stations
Salvar	System of Alert and Visualization of Risk Areas
SF	Spreading Factor
SIG	Geographic Information Systems
Sindec	National Civil Defense System
SNR	Signal-to-Noise Ratio
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TCP	Transmission Control Protocol

TTN	The Things Network
UART	Universal Asynchrounous Receiver-Transmiter
UDP	User Datagram Protocol
USB	Universal Serial Bus
V	Volt
W	Watt
WLAN	Wireless Local Area Network

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Chapter 1

Internet of Things and Smart Cities

The concept of the Internet of Things (IoT) has existed since 1985 and can be defined as the integration of people, processes, and technology with connected devices and sensors capable of remotely monitoring and manipulating such devices (BATTLE; GASTER, 2017). However, it has only been in recent years that the hardware has become cheap enough to enable the practical implementation of IoT, mainly due to the development of embedded platforms such as Arduino, Raspberry, and ESP32, which allow configurations of wireless sensing networks.

According to possible transmission scopes, wireless communication protocols can be classified into 2 categories: short range (Wi-Fi, Bluetooth, Zigbee) and long range (LoRa, Sigfox, RPMA, Weightless) (SAN-URN et al., 2017). In the case of short-range transmissions such as Wi-Fi, there is data transfer of up to 1.3 Gbps, but it only reaches 92 m of range (BATTLE; GASTER, 2017). BLE (Bluetooth Low Energy) has good battery performance but has a transmission rate of only 2 Mbps. Zigbee has restrictions in terms of mobility and sensitivity to noise. LoRa and other long-range technologies reach long distances and with low power consumption, but with reduced transmission speed, putting itself as a rather appropriate alternative for IoT applications.

1.1 Organization

LoRa and LoRaWAN have been chosen as the targets of this project mainly due to the full employability that this technology has for users of IoT technologies. This preference can also be justified by the excellent energy consumption performance of LoRa and also by the fact that it is operated in the free spectrum of frequency, thus there is no need for payment of private fees for use of LoRa technology.

The research methodology of this project was firstly to identify a real application case in which remote sensing is already being employed. Thereby, it is possible to quantify where LoRa would fit in solving applicable problems, under an in-depth study of articles developed by other researchers of the genus. After creating prototypes and running tests that were able to simulate a real case, a code library was customized and presented as a result.

It is a motivation of this work, above all, to carry out an in-depth practical study of an innovative wireless protocol that has a lot of potential for use in the coming years and which will be applied in a significant portion of IoT and smart cities solutions. Moreover, studying an emerging technology opens up several opportunities for differentiated product idealizations and entrepreneurship proposals that can add to the market for embedded systems in dealing with problems in Brazil.

1.2 Contextualization

Regarding Smart Cities, the Inter-American Development Bank (BID) notes:

> *A Smart City is one that puts people at the center of development, incorporates information and communication technologies into urban management and uses these elements as tools that stimulate the formation of an efficient government, which encompasses collaborative planning and citizen participation. Smart Cities foster integrated and sustainable development by becoming more innovative, competitive, attractive and resilient, improving lives. (BOUSKELA et al., 2017)*

Based on this assumption, it is possible to affirm that the creation of intelligent cities based on LoRa technology is not only a social benefit for the present, but also a credit to the whole planet, which gains in sustainability and diversification of opportunities for a pleasant environment. To this end, some researchers have defined a decalogue that must be obeyed to the fruit of achieving such global improvement in the context of smart cities (CUNHA et al., 2016), which are:

1. It is vital that a vision of the city can be constructed in a way that can take into account its particular characteristics, histories and identity, always with broad participation;

2. The leadership of practical implementation of a smart city project is of the public administration, with the leader being the one with the greatest executive power, since he is the one who will be able to define the priorities in the agenda to assure the necessary resources and analyze which collaborations with other agents and outsourced teams will be used;

3. There are several tax challenges, urban zoning, contracting with longer deadlines and well defined objectives, so it is necessary to work within a more favorable legal framework;

4. Vertical services (lighting, waste management, mobility), which are equipped with technology, should be able to interconnect across with the horizontal integration of services (basic public services) to achieve synergies. This feature is the foundation that allows a city to be smart;

5. Make the availability of open data easy in a way that allows transparency, monitoring and information management, as well as the development of new services and activities by companies and citizens, generating value from this prerequisite;

6. All cities should have long-term planning, considering that political party management is temporary and must always have broad participation, good communication and public management aimed at social benefit, ensuring the continuity of projects;

7. A smart city is ideally made from person to person. Therefore, it is important to focus on citizen participation as the core of the process, creating community collaboration methods for problem solving and convenience in considering sociodiversity, as well as attracting and caring for new individuals;

8. The private sector can be a catalyst in terms of development and project sustainability, capable of supporting knowledge, skills and own resources to create new and lasting business models;

9. All the technology involved must be based on interoperable platforms, under the same standard that reaches the widest possible range of equipment, bringing flexibility and lower costs to the city, as well as avoiding dependencies on specific vendors or bold technical structures;

10. All smart city planning must first address the historical problems of these cities, such as those related to safety, health, education, sanitation, housing and social

inequality. In Brazil, in particular, one must also take into account the new demands for mobility that drive economic transformation;

Such standards can be qualified by analyzing holistically how global cities are currently involved in adapting to this transformation.

An annual index of studies developed in Barcelona, Spain, named IESE Cities in Motion (BERRONE; RICART, 2019), has been able to examine all the aspects that make up sustainability and quality of life in 181 key cities in the world, considering not only the performance of cities in relation to technology or the environment, but rather with 106 indicators that cover 10 different dimensions of urban life, such as human capital, social cohesion, the economy, public management, governance, the environment, mobility and transportation, urban planning, international outreach, and technology. With this methodology, a city needs to perform well in several metrics and not just in one area to be considered as one of the smartest cities in the world.

Thus, it was possible to show that the cities with the highest level of integration with the concepts of smart cities are not necessarily those with large territorial proportions or with very high urban density, although the first 10 positions of the study are occupied by megacities such as London (United Kingdom), New York (United States), Paris (France) and Tokyo (Japan). Among the first positions were also noted some medium-sized cities such as Amsterdam (the Netherlands), Vienna (Austria) and Copenhagen (Denmark), and even small towns, as in the case of Reykjavík (Iceland), which shows that the strategic vision of the city to the issue is as important as the technological opportunism that are most common in large cities.

Brazil, however, appears only in position 128 with Rio de Janeiro, 130 for Brasília, 132 for São Paulo, 140 for Curitiba, 146 for Salvador and 151 for Belo Horizonte. A result that is still quite bad compared to Buenos Aires (Argentina), which holds the best placement, 77, of the cities of Latin America.

These facts are capable of denoting the importance of national investment in research on emerging technologies. Obviously, following a standardized decalogue does not mean that developing cities or even those that are already considered developed can successfully implement a project to suit Smarts concepts. This is mainly due to the fact that the inequality in adverse terms between the cities of a country can generate political conflicts that prevent the acceleration and economic growth, culminating in ruptures of projects in progress or negativation of new ideas for a sustainable future. In any case, good planning following standards that worked well in other countries can be taken as a reference.

With this, it can be emphasized that the head objective of this research project is to provide viable solutions for the deployment of IoT in Brazil, proposing sustainable methods to help in the creation of new smart cities. As a specific objective, it can be assumed that in order to provide a viable solution in the national framework, it is expected to provide a base of codes in LoRa (LoBRa) for low cost hardware (whose budget values for the project are not much higher than the costs of prototypes) that can be used freely and still be able to solve real applications problems of remote sensing.

For this, Chapter 2 presents an overview of a natural disaster scenario in which LoRa could be considered as a possible solutions. Chapter 3 shows a theoretical overview of LoRa technology and its foundations. Chapter 4 presents a systematic review of the literature on the LoRa context and its applications in several countries. Chapter 5 expresses the results of experiments with low cost hardware. Chapter 6 shows a final product developed for free use by the Brazilian IoT society. Finally, Chapter 7 concludes the project and in Appendix A, Appendix B, Appendix C, Appendix D, Appendix E, Appendix F and Appendix G important parts of the codes used are shown.

Chapter 2

A case study: analysis and monitoring of natural disasters

From the earliest days of human civilization people have sought ways to optimize spaces for the best adaptation to the needs that society generally demands. These spaces, however, being physical means, are always subject to climatic and environmental changes due to the inclement weather that often influences the survival characteristics of a group of people inserted in certain places. Historical facts are initial constants to be able to formulate studies that benefit us at present or create methods of analysis for the prevention of problems in the future. Cases of tragedies that occurred in antiquity summarize well the need for continuous monitoring of nature's activities. As an example, in AD 62 the Italian city of Pompeii was already suffering from earthquakes that culminated in the final tragedy of an eruption of the volcano on Mount Vesuvius 17 years later (ANTONIO, V., 2012). At that time, numerous people failed to leave their properties and were petrified by the action of the volcano, while the city was under ashes. Today, with the help of innovative technologies, Vesuvius and other volcanoes from various parts of the world are constantly monitored by remote sensing, which prevent when some unusual activity is occurring and may require measures to protect people and buildings from suffering catastrophic damage.

In Brazil, the main types of threats are from floods, landslides, some tornadoes and drought. These are situations arising from rainy periods and also periods of drought, in different regions and can cause serious problems for the general population. One of the most serious natural disasters in Brazilian history occurred in 2011, after a series of rains caused floods and landslides in the Serrana Region of Rio de Janeiro, involving 7 cities, in which 905 people died and another 300,000 were affected by the consequences including buried houses and even individuals contaminated with leptospirosis. Total damages amounted to 4.8 billion, in R$ (FURTADO, 2015). Therefore, the Ministry of Science, Technology, Innovation and Communications established some standards and assigned to Cemaden the national research center with greater responsibility in the context of catastrophe monitoring. For that reason, it is important to first identify the reason for natural disasters to happen, but since some of them are inevitable, it is needed to be resilient and find ways to foresee problems as far in advance as possible to minimize the consequences.

2.1 National Center for Natural Disaster Monitoring and Alerts

The National Center for Natural Disaster Monitoring and Alerts (Cemaden) (CEMADEN, 2018), headquartered in São José dos Campos, SP, is a research unit linked to the Ministry of Science, Technology, Innovation and Communications that was created in 2011 due to the need to manage natural threats such as floods, landslides, fires, adversities in agriculture and other aspects in areas considered at risk for several municipalities in Brazil with potential for disaster incidence and, as a consequence of this premise, be able to foment research in order to prevent such occurrences and reduce the number of victims in accidents, as well as avoiding material damages.

After interviews with Cemaden professionals performed by the authors of this work, it was possible to identify that this type of monitoring is provided to 958 Brazilian municipalities 24 hours a day in the 7 days of the week through different types of sensor equipment.

2.1.1 Organization and main attributes

The foremost lines of research that assist in monitoring within Cemaden are carried out by Technologists, Technicians and Researchers, as well as trainees, outsourced employees and scholarship students. The Technologists are responsible for the development of systems, engineering and infrastructure of Cemaden's analysis processes, the Technician, engineer responsible for maintenance and, finally, Researchers work in the areas of Agrometeorology, Natural Disasters, Fire and Vegetation, Geodynamics, Hydrology, Meteorology and Modeling. Among them, they are divided in the following structure (CEMADEN, 2016):

- Geodynamic Processes Applied to Natural Disasters

  Aimed at the monitoring and mathematical modeling to prevent landslides with the aid of precipitation sensors, soil moisture level and slope displacement by digital terrain models (MDT) and geographic information systems (SIG). It currently provides support to 9 cities with areas at risk.

- Meteorological and Climatological Extremes Applied to Natural Disasters

  It mainly aims to investigate the major factors that contribute to the incidence of extreme rainfall in Brazil and crop collapses.

- Hydrological Extremes Applied to Natural Disasters

  It models the criteria for hydraulic monitoring in urban areas, rivers and basins that are considered potential floodplain areas, as well as their social impact on transport infrastructures on highways and metropolitan areas that the consequences of this type of disaster can bring.

- Vegetation Monitoring and Forest Fires Hazards

  It is concerned about the problems associated with the risk of forest fires that are generally caused by drought.

- Agrometeorological Extremes Applied to Natural Disasters

  Its main objective is the quantification in the database of factors that could lead to collapse of crops and agricultural droughts by means of improvements and applications of phenological sensors and meteorology.

- Vulnerability Associated with Natural Disasters

  It is responsible for the social structuring in the need for strategic mobilization of people in cases of natural disasters and dissemination of data on the dangers of these events, aiming at the resilience of all those involved.

- Data-based Modeling applied to Natural Disasters

  Mathematically analyzes the vulnerability of climate change that causes natural disasters, providing computational prototyping for the measurement of the pre-events responsible for the accidents and enables the creation of a quantitative planning of individuals at risk due to the location with potential for disasters.

Cemaden's working method for monitoring alerts that can cause natural disasters is based on obtaining information from sensors positioned at potential risk locations that communicate with the Cemaden database. In order to obtain this data correctly, Data

Collection Platforms (DCPs), radars and Robotized Total Stations (RTSs) are the responsible equipment that identifies an abnormal condition of the event that is being monitored so that they can be evaluated in time by Cemaden analysts, reaching an observed data flow of 8.36 GB/day, according to the interviews.

As will be exemplified below, DCPs are the most significant equipment for Cemaden, especially pluviometers for the ease in obtaining reliable data and also for the number of already installed DCPs that currently provide real-time data to servers and are monitored all the days. In all, there are almost 5000 DCPs scattered throughout the country (though Cemaden's current management system can support up to 10000 DCPs), while a total of 10 RTSs communicate with prisms (infrared reflectors) also scattered in locations the specific environment in which it is inserted. A prism-RTS assembly can prevent large geological disasters as Figure 2.1 structure.

Figure 2.1: Example of an RTS-prism.

In this scenario, the robotic station sends an infrared signal to the prisms that are strategically located in areas with potential for landslides, for example, so that the signal is mirrored and sent back to the RTSs. The coverage range is up to 2.5 km and if the current positioning value of the prism is displaced relative to a certain data set as "normal" previously, it means that there was a movement in the base of the prism, thus, the signal can be perceived by the robotized station, communicating to the servers of Cemaden (CEMADEN, 2017).

Some examples of DCPs can be seen in Figure 2.2.

- Acqua DCP

  It supports a rain sensor capable of analyzing soil moisture at 2 levels, 10 and 20 cm, shown in Figure 2.2(a).

(a) Acqua DCP.

(b) Pluviometric DCP.

(c) Agrometeorological DCP.

(d) Hydrological DCP.

(e) Geotechnical DCP.

Figure 2.2: DCPs used by Cemaden.

- Pluviometric DCP

  It is mounted with a tipping bucket rain gauge and responsible for the millimetric quantification of the level of rain incident in the place of installation of the DCP, seen in Figure 2.2(b).

- Agrometeorological DCP

  It is a fairly complete DCP that can capture soil moisture and temperature in 4 levels (10, 20, 30 and 40 cm), wind speed and direction through an anemometer, humidity and air temperature through a thermohygrometer, radiation by the pyranometer as well as by the radiometer balance, in addition to also having a pluviometer, according to Figure 2.2(c).

- Hydrological DCP

  It is a level radar pluviometer and a camera for obtaining images, as in Figure 2.2(d).

- Geotechnical DCP

  It is a pluviometer station for analysis of soil moisture in 6 levels (50, 100, 150, 200, 250 and 300 cm), exemplified in Figure 2.2(e).

In all of these platforms there is also a panel for the photovoltaic system with batteries for storing this energy, a processing center and an antenna for data transmission with the mobile telephone network. The data captured by the DCPs are then sent to the Cemaden database and viewed by analysts in the DCP Network Management System (PNMS), which is a status check system for each remote station. In addition to the PNMS, the System of Alert and Visualization of Risk Areas (Salvar) indexes all the important data in a single panel for general monitoring of the whole process, as shown in Figure 2.3, including full observation of the remote sensing network, graphical modeling, live camera imagery, accurate satellite meteorological data, numerical models, interactive maps with occurrence warnings that are constantly updated and listing accumulated information statistics for improvements in quantitative studies.

Cemaden also has partnerships with Sindec (National Civil Defense System) and Cenad (National Center for Risk and Disaster Management), both of the Ministry of National Integration, to trigger in case any emergency measures become necessary.

Figure 2.3: In the background, the Salvar panel.

2.2 Example of a pluviometric DCP

Pluviometers are rain gauges and can be of different types, from the simplest ones that only receive the amount of water accumulated in a demarcated container to those with mechanisms a little more complex, such as by tipping bucket count or optical. The DCPs used for quantification of Cemaden rains are of the tilt type. It was determined to focus on the characteristics of a pluviometric DCP due to the great application of these equipment and the conceptual technical simplicity to exemplify a DCP.

HyQuest Solutions Pty Ltd is a subsidiary company of the German group KISTERS that provides equipment for environmental monitoring, among other activities. One of the products marketed is a bascule type rain gauge and its working principle is idealized in the fact that in the event of a rain, the water is drained by a funnel at the top and directed first to a filter to ensure that possible impurities of significant size do not interfere with the passage of water. Then, the volume of water begins to accumulate on one side of the bascule, which in turn, when reaching the weight limit supported, yields and leans to dump the water accumulated by a "seesaw" effect, in addition to triggering a magnetic metering system (counter) and allow a new pool of water to be made on the other side of the bascule. This process occurs uninterruptedly until the rain ceases.

In Figure 2.4, the TB6 (HYQUEST SOLUTIONS PTY LTD, 2017) tipping bucket rain gauge is verified, manufactured by HyQuest Solutions and separated into 3 parts, from the right to the left: the funnel in which the water is collected from the rain as well as the filter, the cabinet with a front opening for ventilation, and the bascule mechanism that integrates into the bottom of the cabinet and receives water from the funnel . It is worth noting that the TB6 model has an accuracy of water accumulation on the scale of up to 0.2 mm of precipitation collected, which means that a cycle is complete when a bascule has sloped to the side where the accumulation occurred and has triggered the magnetic sensor, enabling the other side of the mechanism to initiate a new accumulation of water and consequently a new cycle. Thus, the sensor communicates with the data processing board and the cumulative value of this counter is sent to the servers. Another important observation is that 0.2 mm means that there was an accumulation of 0.2 l per m^2, or, considering an accumulated water height of 0.2 mm to 1 m^2, there is a total volume of 0.2 l which is equivalent to 200 ml. In summary, each 200 ml of water on the bascule, the sensor is triggered and the data is sent for emergency control, also considering the time it took for the cycle to be completed.

Figure 2.4: Tipping bucket rain gauge.

During the prototyping and construction of the Cemaden equipment, it is of specification of the own bidding that is inserted in the DCPs some mechanisms of control for eventual problems that the equipment can present. In other words, maintenance of the DCPs occurs after the internal control sensors of each station identify that there has been a specific failure in a given circuit, which are also communicable with the servers via the mobile telephone network, as specified:

> The datalogger must allow maintenance data to be stored, such as the open door sensor of the packaging box (state), the external battery voltage (in Volts), the solar panel current (in Amperes), the relative humidity (in %) and the temperature (in °C) inside the packaging box. The reading interval for the maintenance data must be 1 (one) hour (configurable) also allowing the configuration of the time and the interval of transmission of this data. This interval can be set to any value between 10 minutes and 24 hours. The maintenance data transmission routine should be constantly on (PREGÃO, 2013);

Once a fault has been detected in the DCP, a technician can go to the location of the faulty equipment and check the cause of the problem by analyzing the need for some hardware modification or simply make the adjustments to return the unit to normal operation.

2.3 Data transmission of DCP

Regarding the method of data transmission, it is known that the GSM network arose from the need for improvements in terms of digital telephony for the second generation (2G) network and this was due to the fact that the main focus of the 2G equipment was the transmission of data from voice in bits of data to telephone conversations only. In order for a mobile phone or mobile device to have access to the internet, it would be necessary to have a much higher traffic rate. It was then thought to use GPRS technology, which made the communication of data by network protocols. In general, GPRS can be analyzed as an Internet subnet that uses the same protocols. To meet the transmission demand, the GPRS service was included in GSM, creating the 2.5G generation, or GSM/GPRS (SANTOS, 2008). The method of transmission of data collected by Cemaden's pluviometric DCPs is done by the cellular telephone network via FTP using the GSM/GPRS and the tolerance rate for availability of service provision or other quality requirements are determined by the National Telecommunications Agency (Anatel), pursuant to Resolution 574 of October 28, 2011 (ANATEL, 2011). In addition, servers are able to connect to remote sensors over the internet by a dynamic IP enabled by a Cemaden DNS. It is worth noting that in the bidding process, the specifications required as operating requirements are the minimum conditions for the stations to operate properly, but manufacturers are not prevented from implementing the final product with superior technology (such as 4G for transmission of data, for example) as long as this technology is compatible with Cemaden's systems and considering that the carrier that will be used for the equipment in question is determined by Cemaden. The frequency range used for communication is the Quadband for 850, 900, 1800 and 1900 MHz, with a 50 Ohm impedance antenna for gain greater than or equal to 2.14 dBi (PREGÃO, 2013).

2.4 Operating costs

In March 2015, an electronic auction was issued by Cemaden to carry out a tender with the objective of contracting the services of projects and to carry out the installation of 9 Mass Monitoring Sets by RTSs with signal transmission to meet the needs of monitoring in areas susceptible to landslides in Nova Friburgo (RJ), Petrópolis (RJ), Teresópolis (RJ), Angra dos Reis (RJ), Santos (SP), Mauá (SP), Blumenau (SC), Salvador (BA). The whole project, with the reference and reflection prisms, system conditioning accessories, power supply subsystem, atmospheric sensors and GPS installed, integrated a final value for the bidding of R$720,000.00 (PREGÃO, 2015).

Another bid launched by Cemaden was in October 2013 regarding the construction of 1,500 pluviometers with signal transmission via mobile telephones for hydrometeorological control and for an estimated unit value of R$8,439.19, totaling a final investment of R$12,658,779.40, containing the pluviometer, datalogger, conditioning box, cellular modem, solar energy subsystem for power supply and fittings/accessories for field installation, as well as software integrator to the datalogger (PREGÃO, 2013).

It is also subject to bids maintenance contracts aimed at outsourced companies take responsibility for making technical repairs on equipment that suffer some type of failure.

In addition to the Cemaden bids, in the city of Tubarão (SC) there were also announcements in June 2015 related to the investment in monitoring networks for the Municipal Civil Defense Secretariat, and on this occasion the fixed reference value was R$15,300.00 for the construction of a hydropluviometric station, plus the GSM/GPRS data communication structure (R$4,000.00), and also a wireless weather station that included an anemometer, thermo-hygrometer, barometer and rain collector for R$3,800.00 (TUBARÃO, 2015).

It is a fact that the values of bids practiced by Cemaden can not be compared directly with the costs of projects related to IoT, since the objective of IoT is to make feasible projects that do not have structural complexity in terms of prototype composition, which means that the equipment of Cemaden can have expensive functionalities and applications or of high added value, justifying the values demonstrated.In any case, projects with LoRa always present an alternative to the technological options of the moment and, in turn, are closely linked to IoT projects. Therefore, it is increasingly necessary that development costs are justified not only by the importance of the project in which it is being bid, but also by the relevance of applications that emerging technologies have brought over the last few years.

2.5 Desired requirements for DCPs and LoRa

Some situations that are commonplace to Cemaden would bring even more benefits to the control of natural disasters if some improvements in these situations were implemented. As previously stated, the time of sending the files captured by the remote bases is pre-set in 1 hour in dry weather and when there is rain this time can be reduced to a cycle of 10 minutes. However, until the data arrives at the Cemaden monitoring room, some delays are observed, such as the transmission time by the mobile network, processing time in the database, time of visualization, among others. One of the modifications that could be studied is in relation to the process of sending data to the servers and their corresponding decrease in terms of the time needed for this shipment to take place, such as the reduction to a shorter time (5 minutes) in the rainy season. This is a very relevant factor also because the reliability on transmission over the telephone network is something that can cause some disturbances assuming that such networks can suffer signal drops and be out of the air for some unforeseeable period. Another factor that presents some problems relates to the filter clogging in the funnel by natural dirt, such as leaves and dust, preventing water from flowing and falling to the bascule system. A situation that is also due not to a DCP but in the activities of the RTSs is related to the movement of the prisms by human interference, even without intentions in some cases. In this situation, some people can use the prism base as support and interfere with the positioning of the mechanism over time. Finally, an environmental factor that can be difficult to analyze in the RTS data is the vegetation itself that grows in front of the measuring equipment, resulting in the need for a maintenance team to take action and go to the place to cut this vegetation.

Based on these considerations, Cemaden can be pointed as a case study due to the issues of improvements in pluviometric DCPs in the specificity of communication and data transmission, in which LoRa would fit in several ways.

In a first instance, it is important to evaluate the LoRa wireless communication system so that it meets the needs of wireless data transmission over long distances that follow the same quality parameters as the current Cemaden transmissions. This would be a proposal to improve functionality in the whole set of equipment that Cemaden uses and could still function as a redundancy transmission system.

Another point on which Cemaden could benefit from LoRa technology is the sensing of the equipment itself. An ad-hoc network made with LoRa for communication between devices scattered throughout a region could be very useful for preventive maintenance, without the need to aggregate high investment values in bids since the embedded technology would use the DCPs own means for the power supply, support infrastructure and external protection, for example. Even because, as seen, the DCPs suffer considerably with interference from the outside environment (dust, leaves, human intervention), which currently does not have any type of monitoring or efficient prevention system.

However, as negative points, it can be mentioned that LoRa needs a fixed gateway to receive the node data, which may require an infrastructure strategy based on the requirements of the technology. LoRa is also in a very recent developmental version and may present momentary instabilities or version updates with different characteristics, which may require maintenance and local implementation care, in addition to the lack of coverage of a LoRa network, which would be very practical to use of DCPs.

These major reasons encourage further study on how low-cost hardware (based on IoT platforms) could be used to meet such needs.

Chapter 3

Theoretical foundation

In the IoT concept, one of the main features that an application needs is the low power consumption that the transmission method must have in order to enable the exchange of data in relation to the traditional systems of mobile telephone networks and, considering that the communication of Point-to-Point systems in Brazil are usually done by protocols of computer networks or cellular systems, LoRa (Long Range) technology is an interesting solution to meet medium distances between communicators. This is justified by the simplicity and low cost of implementation in general. The applications in Brazil can be of several types: monitoring of climatic conditions, fluid level, positioning of solids (such as volume of dumps in smart cities), public lighting, data collection captured by sensors in material stocks that are sent to screens of controls in logistics companies and of different types of sensing in industries or, the indexing using LoRa of devices of swarm of robots, as in drones for activities of industrial automation, among others. Perhaps the main advantage of using LoRa is energy savings. It is argued that the life of the batteries in a device operating LoRa can reach up to 10 years. Scalability and security, via AES-128 encryption, are other features that LoRa has to improve the suitability of each particular system (ADELANTADO et al., 2017).

In Belgium, the country's largest telephone company, Proximus (PROXIMUS, 2017), has implemented in its portfolio an IoT system using LoRa that is being used to control countless variables, such as temperature, humidity, air quality, light, gas, fluid level, electricity, garbage quantity analysis, wizards vehicles and others. In the operating premise, the service is sold both from the communication part between sensors and gateways via LoRa and in the part of the transmission of the gateways to the application servers, via 2G/3G/4G or WLAN, in a complete package to the client.

In South Korea, LoRa is being implemented by SK Telecom (SK Telecom, 2017) with an application of smart cities. Considering that for the analysis of electricity, gas and water consumption meters, manual conferences were carried out by operators, now the service is done automatically and sent to a remote database by the LoRa transmission. This idea is also interesting by the possibility of visualization of consumption by the users, who can have in a mobile application the quantitative analysis of the expenses in their residence by graphs and even alerts of problems in the electrical network.

In the Netherlands, LoRa is being used with GPS in services provided by the telecommunications company KPN (KPN, 2017). In this case, partnerships with logistics companies allow identifying the location of cargo or delivery within large centers, optimizing the method of parcel distribution.

Based on these examples, it is possible to note that the application of LoRa in the telecommunication segment has great potential and as previously mentioned, a useful application of LoRa in Brazil would also be in the monitoring of natural disasters carried out by Cemaden, which in this case the transmitter could handle implementation costs and would transmit the information captured by some types of DCPs to send to the servers. A cheap solution, easy to adapt to existing equipment and independent of the operation of telecommunications companies.

3.1 LPWAN

LPWAN (Low Power Wide Area Network) is a low-power, low-cost, wide area coverage and low data transfer wireless communication that is designed to meet the growing demand for IoT equipment (PETÄJÄJÄRVI et al., 2017a). Examples of LPWAN technologies include LoRa (SEMTECH, 2017), in which this work will focus, Sigfox (SIGFOX, 2017), RPMA (INGENU, 2017) and Weightless (WEIGHTLESS, 2017).

3.2 LoRa

LoRa, is a physical layer modulation technique patented by the French company Semtech (CORPORATION, 2017; ALLIANCE, 2017c, 2017b, 2017d), which can be used in the unlicensed radio frequency spectrum for data transmission, including ISM band and U-NII band (TELECO, 2017). The proposal of LoRa is to enable a wireless communication technology that meets the LPWAN premises at a low implementation cost and to make viable through a communication standard called LoRaWAN the interconnection of several separated devices by a long distance without the needs of complex systems transmitters and receivers.

3.3 LoRaWAN

LoRaWAN is a data structure convergent to the LPWAN that defines the network protocols and the system architecture by specifications standardized by the LoRa Alliance (ALLIANCE, 2017a),which is a company formed initially by members of the industry and aims to improve and define the characteristics of LoRaWAN.

Figure 3.1 presents the layered organization of LoRaWAN. At the top level are the applications, which through specific APIs will make use of LoRa communication. The architecture and specification of LoRa and LoRaWAN can be found in (SEMTECH, 2017; ALLIANCE, 2017c, 2017b, 2017d). The following summarizes some of its key features.

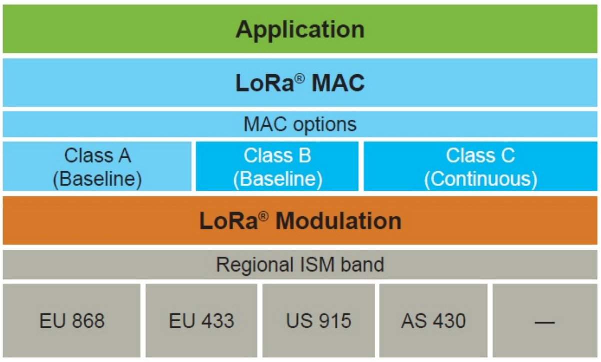


Figure 3.1: Layers of the LoRaWAN protocol (ALLIANCE, 2015).

3.3.1 The technology

The LoRaWAN is based on star topology, which connects the sensors (also called "motes" or "nodes") to communicating gateways with servers. Communication between the nodes and the gateway is done through LoRaWAN, while the transmission of data from the gateway to the network and application servers is performed via standard IP internet protocols, but in both steps are always bidirectional methods and use different frequency and data rate channels (SEMTECH, 2013).

In relation to the nomenclature attributed to the steps of sending data between nodes and gateways, it can be affirmed that the term used to refer to the data sent from the nodes to the servers by the gateway is uplink, whereas downlink refers to the data that is received us through the gateway via servers.

In Figure 3.2, the architecture of LoRa can be included. The nodes capture the data that is being monitored and communicate with the respective access gateways to the servers, after which it is possible to view the information in data management applications.

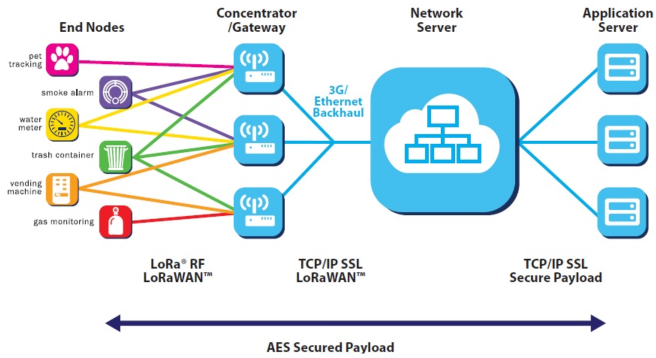


Figure 3.2: LoRa Architecture (ALLIANCE, 2015).

The data sent by the nodes can be received by more than one gateway, making it the task of the network server to manipulate and manage data in redundancy. This server can also be the same as the application server.

3.3.2 Physical Layer

At the physical layer, LoRa employs a modulation technique based on Chirp Spread Spectrum (RAPPAPORT, 1996). Chirp technology was developed by military personnel during World War II, its initial purpose was to distort the signal to confuse the enemy troop. It basically consists of varying the frequency of transmission in a linear way (JUNG; LI; LEE, 2015; BERNI; GREGG, 1973). By spreading the transmission in the frequency spectrum of the channel, instead of using only the center frequency, LoRa manages to reduce transmission power, resulting in a low signal-to-noise ratio (RIZZI et al., 2017); by the way, the signal level is usually less than the noise level. This technique offers greater resilience to external interference (RAPPAPORT, 1996).

3.3.3 MAC layer: element classes

There are 3 classes of nodes that serve different types of applications and therefore can be divided according to the specific needs of each node.

- **Class A: Two-way transmission.** In this class, nodes can receive data only after a data transmission, that is, transmission windows are limited and predetermined.

- **Class B: Bidirectional transmission with scheduled transmission windows.** Here, for the transmission to occur, nodes and gateways exchange messages requesting permission to send the data packets.

- **Class C: Semi-open bidirectional transmission.** In Class C the gateway is always open to receiving data from nodes except when the gateway itself is transmitting, and is ideal for connections where the downlink is most requested.

Class A is used, fundamentally, when the objective is the energy optimization of the sensors, but can generate a greater delay in the delivery of packages. In Class B, packet delivery delays are controlled, but power consumption increases with the possibility of downlink. Class C has the best performance over packet delivery without delay, but it is the class that consumes the most power.

The operation class of a node is an adjustable transmission requirement, as are other parameters that influence communication, such as spectral spreading, usable bandwidth, and bit-encoding rate. The settings of these parameters may involve the programming of the embedded systems and the configuration of the network servers (ALLIANCE, 2015).

3.3.4 Technical specifications and operating mode

It is important to highlight some topics inherent to the mode of operation of the networks that work under LoRaWAN. These concepts are intrinsic to the coding method used in the transmission and coordination of data by both sensor nodes and gateways. However, the operating characteristics are subject to the current laws and restrictions of each region or country in which the LoRa is being used. As a consequence, some technical regulatory committees in certain regions have not yet established a definitive criterion for the technical operating requirements and therefore the standards of some items relevant to the LoRaWAN configuration (such as free frequency range for use, number of channels, bandwidth, among others) do not follow the same for Europe, North America and Asia, for example.

- Range

  It is the maximum range that a data package can travel without losing its characteristics and can be influenced by several factors, such as temperature, humidity and rainfall adversities, for example. With only one gateway, LoRa manages to reach tens of square kilometers, depending on the type of environment that exists between the sensor node and this gateway (TELECO, 2017).

- Bitrate

  It is the amount of bits per second that can communicate between 2 devices in some medium, usually associated with data traffic. It is worth differentiating that throughput is the amount of usable information that is transmitting and that is effectively received by some final destination. In LoRa, this bit rate can range from 290 bps to 50 kbps (SEMTECH, 2017).

- Sensitivity

  It's how far a sensor can be from a gateway. It is related to the transmission power, antenna and geography of the location in which the system is implemented. The more open and unobstructed it is, the more sensitivity it will have.

- Time-on-air

  It is the time that a packet remains in the air after sending through a sensor node and received at a gateway. This time can be viewed on the cloud server and varies according to the spreading factor used and environmental conditions.

- Energy consumption

  The power used for transmission as well as the spreading factor adjustments determine how much power should be used to meet the needs of the system. However, it is characteristic of technologies for IoT and one of the main strengths of the LoRa is the low consumption and the high durability of the battery because in the moments in which there is no transmission or reception of packages, the equipment can stay in standby. For a common LoRa SX1272 chip, a transmission under 20 dBm consumes an average of 412.5 mW.

- Adaptive Data Rate (ADR)

  The ADR is a function that allows to adjust the data transmission according to the application. This means that in a short distance transmission it does not need a spreading factor greater than 7 or 8, if it is configured to transmit SF = 12, and there may be more than enough power consumption, so the ADR identifies and modificate the transmission rates.

- Latency

It is the delay that a packet has during sending and receiving on broadcasts. Directly related to airborne weather, latency is also a factor that is determined according to the geography in which the system is implemented and together with bandwidth, can define the speed at which a packet will exit the source and arrive at destination gateway.

- Safety

  To create transmission security, an AES 128 algorithm is capable of generating a series of keys that function as an XOR with the data. Therefore, the network and application keys are identified by the server and can validate the transmitted information.

- Package size

  The maximum size of 242 bytes in theory can be reached with a scatter factor equal to 7, but there are limitations in libraries (LMiC) that greatly restrict this rate, being able to reach less than 64 bytes as a packet limit (with 13 header bytes), to 915 MHz. In any case, the recommendation is to use the smallest possible packet, idealizing 12 bytes as the best case, highlighting the fact that LoRa and LoRaWAN were created mainly for Internet demands of Things and remote sensing, which does not requires large byte capabilities.

- Data Rate

  It is defined as the exchange between a period of communication and the duration of a message, that is, a specific organization of coding and modulation of data that varies according to other parameters, such as bit rate, bandwidth, signal sensitivity and spreading factor.

- Power transmission

  It is a measure that can be quantified by dBm or mW and, in general, shows how significant a signal can be in relation to the maximum range of the system, depending on the transmission limitations imposed by each region.

- Bandwidth

  It is defined as the frequency range at which it can be used to transmit information under the operating frequency. Thus, 125 KHz has fewer frequencies available for use compared to 250 KHz in channel variations for 915 MHz or any other.

- Spreading factor

  Also called SF, it is how condensed the bits are to be sent, and they range from a scale between 7 and 12, so that a spreading factor with a smaller index means smaller range but with a higher data rate compared to spreading factor 12, which can reach greater distances by an energy consumption and time in the air also larger.

- Frequency of transmission

  Also defined as operating frequency, it is the radio channel that is transmitting the data and in most application cases can not be adjusted in the settings since the hardware also depends on this frequency. In this case, the purchased LoRa transducer modules have already been selected for an operating frequency of 915 MHz.

- Coding rate

  It is defined as the rate of valid transmitted information that relates the number of useful bits by the total number of bits in the packet. Thus a CR 4/5 means that there is 4-bit usable data transmission for every 5 total bits.

3.3.5 Expected performance

The performance that LoRaWAN can theoretically achieve is 27 kbps (and 50 kbps using FSK) maximum rate for data transfer, considering the different spreading factor settings for 915 MHz and number of 64 channels for uplink and downlink, which can be disabled if they are not in use (ADELANTADO et al., 2017). The battery runtime for an autonomous system is estimated to remain active for approximately 10 years with sensitivity between the sensor node and receiver node up to -136 dBm using bandwidths of 125, 250 and 500 kHz, without transfer limitation of packets and integrated with a cloud server to quantify the data sent. The expected range is 5 km for urban areas and 14 km for rural areas or without significant obstacles between the transmitter and receiver, while on the surface of the water there are results with a range up to 30 km (PETÄJÄJÄRVI et al., 2015a). Other authors (ADELANTADO et al., 2017), on the other hand, verified that critical monitoring of infrastructures (in real time) requiring fast response actuators may not be a good application of the LoRa system, even with the smallest spreading factor possible that can take up to 40 ms to effect a sensor response by transmitting a small packet (10 B), although other industrial activities with less need for active response can benefit from the technology.

In general, LoRaWAN is expected to be able to prove itself as an efficient technology for remote monitoring and an alternative to applications that are already in use today by natural disaster control centers instead of the conventional method of transmission (3G).

3.3.6 Limitations in Brazil

At the bottom of Figure 3.1, it is possible to be observed a parameterized layer that is defined according to the area of use of the protocols. This specification can be found in (ALLIANCE, 2017a). Among the parameterized values are, for example: frequency bands, channels, transmission medium usage time, maximum transmission power and waiting interval in backoff (ALLIANCE, 2015). By separating the algorithms and the operating parameters, LoRa and LoRaWAN simplified the hardware projects and their suitability to the different realities; it is noted, however, that a LoRa device must have its operating frequencies set to operate in different regions. The Table 3.1 shows the operating frequencies of LoRa in some regions. These frequency bands are part of the ISM free spectrum of the sub-GHz bands.

Table 3.1: Operating frequencies in the free spectrum (ISM)

Local	Frequency (MHz)
Europe	867-869
North America	902-928
China	450-510
Japan	920-925
India	865-867
Brazil	902-907.5 e 915-928

Note that in Brazil the ISM band is not continuous. This range of operation was continuous (from 902 to 928 MHz) until 2006, when the Federal Government published Resolution 454 giving up an interval – breaking the segment into 3 parts – for the use of cellular services (ANATEL, 2018). With the resolution of Anatel, instead of 902 to 928MHz, only the frequencies of 902 to 907.5 and of 915 to 928MHz would be free. In Brazil, the LoRa RFM95W-915S2 transducer chip has been approved by Anatel since December 26th 2016, however there are still no end products with the chip in use and, therefore, can be re-evaluated by Anatel when some integrated module enters commercial status. In this model of transducer, the operation is performed between 902.0 to 907.5MHz and also between 915.0 to 928.0MHz, having to respect the maximum output power of 0.0653W for both frequency ranges (HOMOLOGAÇÃO, 2017).

Chapter 4

Systematic review of related work

This section will address a systematic review of studies already developed and published in the literature to find sufficient technical background that allows the creation of a methodology of practical tests and documentation of such tests. The methodology adopted was based on the selection of articles that answer the research questions listed below and that allows to qualitatively evaluate the studies according to each branch of application (KITCHENHAM, 2004).

Figure 4.1 shows the flow of the research process from this systematic review. Initially, in Phase 1, the IEEE Xplore Digital Library (IEEE, 2018) database, ACM Digital Library (ACM, 2018), Springer Link (SL, 2018) and ScienceDirect (SD, 2018) were used with the key words LoRaWAN, LoRa, LPWAN and IoT under keyword search aggregation method with the connector **AND**. In Phase 2, the results that showed suitability for the title or abstract were considered. In Phase 3, primary screening was performed for an indepth study of the articles that in Phase 4 were reclassified by exclusion criteria. Articles that met all the requirements are part of Phase 5.

Figure 4.1: Flowchart of the research methodology

Regarding the exclusion criteria of Phase 4, all the scientific papers published before 2015 (the year in which version 1.0 were released) and only those written in English were considered, since these articles have a greater international scope and attend non-speculative LoRa technology situations. Thereafter, the resulting articles are routed through the last step, Phase 5, whose function is to determine a separation analysis in branches of activities in which the resulting articles fit, which meant in practical terms in separating all articles into 3 groups: Application, Theoretical and Experimental, according to Table 4.1. Thus, the group of Application articles contemplated all the cases in which the LoRa technology helped to solve some real situation. The Theoretical group was formed by articles that studied in more depth the themes inherent to LoRa but did not perform any field implementation activities. The group of Experimental cases consists of articles that underwent tests with LoRa but also did not envisage practical application.

This study focuses on articles from the first group (Application) because in them are situations in which the use of LoRa is created for a specific purpose and for this to be achieved, the authors had to previously have completed studies of all theoretical functions and validated the experiments in laboratories, so that after these considerations they could use the concepts in solving some problem.

Table 4.1: Number of articles per database

Type of work	***IEEE Xplore***	***ACM***	***Science Direct***	***Springer Link***	**Total**
Application	59	4	4	4	**71**
Theoretical	51	4	9	7	**71**
Experimental	22	3	2	2	**29**
Total	132	11	15	13	**171**

The list of published works by country can be seen in Table 4.2. It is worth mentioning that some works were developed in partnerships between universities of different countries and therefore were classified as works in partnership.

Some works have determined analogies between LoRa and LoRaWAN with the computer network model of the OSI layer. LoRa integrates the physical layer while LoRaWAN the network layer, if this technology is seen by the OSI model.

In Bucharest, Romania (ANDREI; RADOI; TUDOSE, 2017), the hardware was prototyped and thus the maximum transmission distances reached using LoRa in different parts of the city could be validated. In this study, it was also verified that using a STM32 development board (Cortex-M4 with a SX1272 module) and a SF7, CR (Coding Rate) 4/8 manufacturing shield, a range of 4.3 km in urban area and 9.7 km in rural area with Gateway antenna (GW) positioned in high places. In addition, it was reported that an Arduino would not be able to operate as a real GW because it only possessed 2 kB of SRAM.

In the studies done in Lisbon, Portugal and Pittsburgh, USA (DONGARE et al., 2017), a similar prototype (OpenChirp) was also found analogous to the OSI layer. Ac-

Table 4.2: Country of origin of publications and quantity of articles

Local	Qty.	Local	Qty.
Argentina (GRIÓN et al., 2017) (CANDIA et al., 2018)	2	Japan (BOSHITA; SUZUKI; MATSUMOTO, 2018)	1
Australia/Russia (FEDCHENKOV; ZASLAVSKY; SOSUNOVA, 2017)	1	Kazakhstan/Russia (TIKHVINSKIY; KORCHAGIN; BOCHECHKA, 2017)	1
Australia (RADCLIFFE; CHAVEZ; BECKETT, 2017)	1	Lithuania (NAKUTIS et al., 2018)	1
Belgium (LAVEYNE; ZWAENEPOEL; EETVELDE, 2017) (PODEVIJN et al., 2018)	2	Macedonia (DAVCEV et al., 2018)	1
Brazil (BARRIQUELLO et al., 2017) (FILHO; FILHO; MORELI, 2016) (CARRILLO; SEKI, 2017) (SILVA et al., 2018)	4	Malaysia (NOR; MUBDI, 2017) (ASSRI; ZAMAN; MUBDI, 2017) (IBRAHIM et al., 2018b) (IBRAHIM et al., 2018a) (IBRAHIM et al., 2018c)	5
Bulgaria (PENKOV; TANEVA; KALKOV, 2017) (HRISTOV et al., 2018) (MATEEV; MARINOVA, 2018)	3	Morocco (KARKOUSH; MOUSANNIF; MOATASSIME, 2018)	1
China/England (YU; ZHU; FAN, 2017)	1	Netherlands (AYELE; HAKKENBERG; MEIJERS, 2017)	1
China (LI; XIAO; LIU, 2018)	1	Pakistan (ARSALAN et al., 2018)	1
Czech republic (GOTTHARD; JANKECH, 2018)	1	Romania (ANDREI; RADOI; TUDOSE, 2017)	1
Denmark (FARGAS; PETERSEN, 2017) (BARDRAM et al., 2018)	2	Scotland (WIXTED; KINNAIRD; LARIJANI, 2016)	1
England (BATTLE; GASTER, 2017)	1	Serbia/Slovenia (KOS; MILUTINOVIC; UMEK, 2017)	1
Finland (PETÄJÄJÄRVI et al., 2017b) (PETÄJÄJÄRVI et al., 2015b)	2	Singapore/Myanmar (THU et al., 2018)	1
France/Ireland (HAVARD et al., 2018)	1	South Korea (JEON; JU; YOON, 2018) (PARK; HWANG; KIM, 2017)	2
France (NEUMANN; MONTAVONT; NOËL, 2016) (VARSIER; SCHWOERER, 2017) (LORIOT; ALJER; SHAHROUR, 2017)	3	Taiwan (CHOU; MO; SU, 2017) (KE; LIANG; ZENG, 2017) (LEE; KE, 2018) (LIU et al., 2018) (WANG et al., 2018)	5

Germany/Tunisia (MDHAFFAR A., 2017)	1	Thailand (VATCHARA-TIANSAKUL; TUWANUT; POR-NAVALAI, 2017) (SAN-URN et al., 2017)	2
Germany (POENICKE et al., 2018)	1	Tunisia (RAHIM; GHAZEL; SAIDANE, 2018)	1
Greece (ZINAS et al., 2017)	1	Turkey (AL-TURJMAN, 2017)	1
India (JAMES; NAIR, 2017) (SA-HOO; PATNAIK, 2017) (GEETHA; GOUTHAMI, 2017) (MANOHA-RAN; RATHINASABAPATHY, 2018) (SALPEKAR; GUPTA; TEJAN, 2017)	5	Uruguay (BELLINI; AMAUD, 2017)	1
Italy/Sweden (RIZZI; FERRARI; FLAMMINI, 2017)	1	USA/Finland (HÄMÄLÄINEN; LI, 2017)	1
Italy/Turkey (BUYUKAKKASLAR et al., 2017)	1	USA/Portugal (DONGARE et al., 2017)	1
Italy (CARVALHO et al., 2018) (FERRARI et al., 2017) (US-MONOV; GREGORETTI, 2017) (BONAVOLONTA; TEDESCO; MORIELLO, 2017)	4	USA (DANIELETTO; LI; DUD-LEY, 2017) (JALAIAN et al., 2018)	2

cording to the authors, layers 1 and 2 (Physics and Liaison) correspond to LoRa and layers 3 and 4, LoRaWAN (Network and Transport). OpenChirp would be analogous to Layer 5, 6 and 7 of OSI (Session, Presentation and Application), that is, constituted with LoRa and LoRaWAN, Open Chirp has autonomy to aggregate metadata and services as web interface and storage to the 8 B received.

In addition to these analogies, in Bangkok, Thailand (VATCHARATIANSAKUL; TUWANUT; PORNAVALAI, 2017), has been clarified the Classes in which equipment with LoRa fit, that is, the labeling of equipment LoRa according to the application needs:

The battery runtime for a stand-alone system is estimated to remain active for approximately 10 years with sensitivity between the sensor node and receiver node up to -136 dBm using bandwidths of 125, 250 and 500 kHz, without transfer limitation packets and integrated with cloud servers for quantification of sent data (LEE; KE, 2018).

4.1 Which are the type of application in which LoRa and LoRaWAN are being used?

As detailed below, there are several applications for LoRa technology that are currently employed.

4.1.1 Applications in Smart Cities

GPS is the most commonly used technology for vehicle tracking. Nowadays, there are GPS buses for tracking and collecting traffic data and other variables. Cellular networks are also used, but GPS technology is not the most appropriate for this type of activity since it uses an average of 70 mA for tracking while LoRa can be optimized to consume much less (2.8 mA on, 38.9 mA transmitting and 14.2 mA receiving) (FARGAS; PETERSEN, 2017).

In India (JAMES; NAIR, 2017), some buses are equipped with transceivers and bus stops with receivers (nRF24L01 transceiver integrated to PIC18F and ESP8266). Soon, when the bus arrives at the point, the Tx-Rx transmission is made and a LoRa module located at the bus stop can transmit the location information to a gateway at 4 km. In this type of control, it is possible to visualize the last stop of each bus and its respective stop time, among other information. In an integrated way, in Nagoya, Japan, it was possible to track the location of buses using such transceivers at bus stops with a LoRa AL-050 next to an Arduino Uno and GPS U-blox NEO-7N to capture bus positioning in time real. As a gateway, a Kerlink Wirnet Station 923 was used. A Raspberry Pi 3 with Visionect 13.3-inch e-paper was also used, operating as a web server on Raspberry Pi for data received in JSON format. With these configurations it was possible to reach up to 2.1 km and to validate the technology in a practical way, since, according to the authors (BOSHITA; SUZUKI; MATSUMOTO, 2018), there are still not many studies about LoRaWAN applications with fast moving nodes and, therefore, it seems that for nodes in motion above 50 km/h, data is already compromised.

In Argentina (GRIÓN et al., 2017), Cordoba and Buenos Aires are cities that already have LoRa networks implemented with nodes made of BeagleBone Black, GPS, and LoRa module. Already the gateway, a Multitech MultiConnect Conduit interconnected with the network server The Things Network. The good range achieved of 5 km in urban areas in both cities allows concluding that the Beaglebone Black can be used as an IoT device, but with relatively high consumption (500 mA during the tests).

In South Korea, a network that reaches 99% of the population is being developed using LoRaWAN, while Amsterdam, the Netherlands, was covered entirely with 10 gateways (BATTLE; GASTER, 2017) (AYELE; HAKKENBERG; MEIJERS, 2017). London and surrounding areas, United Kingdom, are already adequately covered by LoRa (YU; ZHU; FAN, 2017). In this study, the efficiency of the protocol to assist in the monitoring of air quality and urban congestion is proven. Also, it was found that the battery life decreases with the increase of the package. The LoRa system is reliable because it obtained an average throughput of 405.5 bps for the central area and 269.2 bps for the farthest area. The total project cost of 11,681 nodes and 47 gateways exceeded one million pounds for a financial return in up to 7 years, mainly explained by the costs of installing, maintaining and leasing local infrastructure, which corresponds to 90% of the investment.

Authors in Yangon, Myanmar, and Tampines, Singapore (THU et al., 2018), have created sensors (with The Things Uno) that capture temperature, humidity, dust, and carbon dioxide in the air. The gateway (Laird) receives such data and communicates with the TTN, which in turn communicates with a proprietary bank (via MQTT) for data visualization by Grafana and also for such data to be used for machine learning. These studies have considerable social relevance because, according to the authors, a person breathes in approximately 11,000 liters of air every day, while 7 million people die every year from air pollution-related diseases. Air quality monitoring was also studied in La Plata, Argentina (CANDIA et al., 2018). The authors used sensors created with the processing of an Arduino Mega and 5 Kerlink iBTS gateway model for signal reception to monitor particulate material (PM), which represents the rate of pollution that is contained in the air and which can cause cancer. In the same scenario, some authors from Manouba, Tunisia (RAHIM; GHAZEL; SAIDANE, 2018), focused on the feasibility of non-packet transmission with a LoRaWAN network implementing a sensor network in a city to monitor air quality. The transmission power was 14 dBm for a range of up to 6 km (7 B packs and 20 B payloads, 13 for the header). It was simulated a multiple packet sending environment to obtain the reception rates, proving that for the increase in the number of nodes, there is a decrease in the number of packets received. Complementary studies also indicate that there is a correlation between the high temperature with packet loss rate and, therefore, it is made explicit that there is a direct proportion between these quantities (WANG et al., 2018). These findings were obtained from tests carried out in Hsinchu City, Taiwan, where the authors state that for transmission of 20 dBm of nodes and payload of 11 B, in addition to the power supply from a 10000 mAh power bank, it was possible to monitor air quality on a university campus. Both Arduino and Raspberry Pi were used in these tests as processors of the data captured from the sensors.

In St. Petersburg, Russia, waste management applications were developed through LoRaWAN. In this case, it was found, using Arduino and Raspberry Pi, that 1 kbps is sufficient to connect volume sensors in public dumps to garbage trucks and landfills or recycling factories, allowing the visualization of the data in servers via Node-Red and NodeJS for applications (FEDCHENKOV; ZASLAVSKY; SOSUNOVA, 2017).

Also in the Smart City segment, a GY-271 magnetic sensor, Seeeduino LoRaWAN with GPS for the node and a Dragino Lora-GPSHAT with Raspberry Pi 3 for gateway were used in Selangor, Malaysia, with the aim of improving the traffic monitoring in denser urban areas in Malaysia, where there are intense vehicle flows and thus enables the management of vehicle passage at the proposed locations. The cloud server used was Digital Ocean and Grafana for data visualization (NOR; MUBDI, 2017). It is important to emphasize, above all, that the delay time in delivering messages with LoRaWAN in an urban network of fixed and moving sensors must also be studied since, with the growth of urban applications, the network with the sensors would be increasingly congested. Using a Siemens IOT2040 device with Yocto with a Microchip LoRaWAN dev kit (DM164138 comLoRa modem RN2483) as a node for data collection, some authors in Brescia, Italy (CARVALHO et al., 2018), could cover an area of 3.3 km^2. To evaluate variables in non-real time of application, such as the volume of dumps and monitoring of heaters. The maximum delay for both fixed and moving nodes was 250 ms due to the quality of the internet (using the NTP protocol), which is sufficient for non-real time IoT applications.

With similar hardware, except for the magnetic sensor HMC5883L, it was also tried to implement in Selangor a system of control of vacancies in parking lots with the aid of LoRaWAN, in which the vacancies are detected by the sensor and informed to a central database. Such projects are considerably cheap considering the components that integrate them (ASSRI; ZAMAN; MUBDI, 2017) (JEON; JU; YOON, 2018).

Evaluating free spots for boat spots in the harbor can also be allocated as a LoRa location-related for smart applications. In Kongens Lyngby, Denmark (BARDRAM et al., 2018), some authors created a prototype made with Seeduino and an ultrasonic sensor as a node to detect the presence of a boat in a particular spot. The prototype built with a LORANK8 for gateway and a LoRa RN2483 transceiver module located 2 m in height could be monitored through a mobile application that was created for better contemplation of the system. An extensive study was conducted on the number of packet collisions by increasing the number of devices in a simulated system (SF7 had a lower incidence of collisions compared to SF12) and, in practice, the tests were satisfactory. With a similar practical ideology, some authors in Brno, Czech Republic (GOTTHARD; JANKECH, 2018), have developed solutions to assist in the management of large car dealerships that are displayed on courtyards, since a customer may have to wait a long time before the establishment's employees find the location of the vehicle. In this type of scenario, the principle was to monitor the return time of the nodes per ICMP packets to evaluate the RSSI and quantify the distance. The specifications of the nodes were: microprocessor ARM Cortex-M0 + with 5.5kB RAM and 57.4kB flash. In the end, it was suggested that, for this field of application, 2 gateways should be used for better information routing.

There are also works related to urban implementations of LoRa that were developed focused on business activities; that is, the use of IoT in buildings and office environments.

In Strasbourg, France, the operation of a LoRa transmission in the urban environment was detailed and showed that the consumption does not reach 40 mA using a Raspberry Pi 2 with IMST IC880A in the gateway and with RN2483 in the nodes. In these tests, it was defined the sending of a packet of 17 B, 4 B of useful information and 13 B of other data (header and MIC), in addition to established power of 14 dBm to meet the need for data transmission (NEUMANN; MONTAVONT; NOËL, 2016).

In Melbourne, Australia (RADCLIFFE; CHAVEZ; BECKETT, 2017), in a Business Center, it was obtained an efficiency of 200 m in reach for transmissions without loss of package, and it was shown that in 600 m no package was received. Here an omnidirectional antenna BY-915-06-03 located 40 m above the ground was used for the gateway (MultiConnect Conduit - Multitech), 11 B packet and 1 packet transmission every 30 s.

There are LoRa applications to meet residential and building automation demands with LoRa as well. Studies in Lille, France, and Limerick, Ireland (HAVARD et al., 2018), have shown that the use of spectral mirroring facilitates the passage of data through walls and obstacles. Therefore, the authors have created an integration with LoPy devices, which have short range protocols, to communicate with LoRa concentrators. The sensors used that communicated with the LoPy were integrated with ESP32. A gateway was inserted into the system to be able to send the data to an external server so that such data could be viewed by the TTN.

To assist in DHL cargo management at an airport in the Magdeburg region of Germany

(POENICKE et al., 2018), some authors have addressed the fact that the embedded systems capable of monitoring cargoes on luggage platforms must withstand extreme temperatures, snow, rain, fluids and other types of stresses. Based on these conditions, sensors were placed on the load conveyors (more than 1700 nodes) that communicate with a central gateway for quantification of the data and, therefore, it was possible to evaluate by simulations the conditions of loads of the transporters, although tests in the field have not yet been completed.

In Glasgow, Scotland, a generic study was done using Kerlink as a gateway and as a knot a Raspberry Pi with a Multitech mDot, powered by a 5V USB FTDI, aiming to test the use of LoRa in an urban setting to send data via a node for a gateway located in positions favorable for transmissions. The results were 1.9 km in range, with rates of 42% utilization, and with 2 gateways, the rate rose to 70%. Some receive failures were associated with gateway-server transmission and not with LoRaWAN. The topography of the test site also disrupted the results (WIXTED; KINNAIRD; LARIJANI, 2016).

In Tainan, Taiwan, the usability of LoRa was shown to create a vehicle condition monitoring system by implementing sensors at specific vehicle locations to obtain data and transmit to a nearby gateway. An Arduino was connected to the OBD-II via UART to obtain the data of some component of the vehicle, like engine or brakes. A Gemtek LoRa module sends the data to the gateway receiver (node and gateway Gemtek), and then packets are transmitted to the cloud platform by MQTT, which use TCP/IP for internet connection. Although it can not transmit large amounts of information, it has been proven that a vehicle condition monitoring system can be done with LoRa (CHOU; MO; SU, 2017).

This work can be integrated with the one developed in Marrakesh, Morocco (KARKOUSH; MOUSANNIF; MOATASSIME, 2018), in which a system capable of implementing a camera is shown in the windbreak of the vehicles, thus detecting if a driver slept while driving, in which case he will be alerted, among other functions of control for the vehicle and perceptions. Communication with a database is done by LoRa, and the prototype was developed with a Raspberry Pi and an RPi camera.

On the control of urban pollutants in New York, USA (DANIELETTO; LI; DUDLEY, 2017) LoRa was used to create a device that monitors the air in different neighborhoods, spreading the sensor network through such locations and creating communication with the data server. This work has shown that air pollution can cause numerous health problems and identify environmental risks in specific regions. An ARM-M0 Cortex processor and 1000 mAh battery were used, and the data server was implemented in Amazon Web Services. Based on this experiment, the authors could note that there are several types of air pollution in different neighborhoods.

4.1.2 Applications in Smart Grids

For LoRa solutions with Smart Grid, in Santa Maria, Brazil a experimental implementation, in the rural area, of 130 nodes were used using LoRaWAN adjusting the antennas gain to cover the entire node scenario and the time of receiving packets, with the objective of showing good protocol efficiency with applicability in Smart Grid for these locations. A smart energy meter does not need human interference for consumption validation, transmitting data at each predetermined time to a control center. Currently, there are options for monitoring smart grids with sub-G mesh RF networks with a maximum data rate of 10-100 kbps, which is very useful in terms of reach and energy but compromised in latency. In this case, the authors stressed the precepts of modulation by Chirps. On this, one of the relevant items addressed was the fact that if there is transmission at the same frequency and the same SF, decoding may occur if the difference between the 2 signals is at least 6 dB. It has also been specified that the regulations pertaining to the test site for EIRP, i.e., the product of transmitter power and antenna gain, is 36 dBm with the observation that a commercial LoRa SX1276 transducer uses up to + 20 dBm and has a sensitivity of -137 dBm to 125 kHz and SF12 (BARRIQUELLO et al., 2017).

The studies developed in Campinas, Brazil, were also dedicated to the applications of Smart Grid, in which the authors evaluated if LoRaWAN can supply the needs of remote sensing in this field comparing 2 technologies, Mesh RF and LoRaWAN. It has been shown that a system with LoRaWAN costs 5 times less than an RF mesh system, in addition to LoRa being able to aggregate up to 15,0000 devices in a gateway. As a result, it is stated that although the 2 technologies are relatively recent (Mesh RF 2012 and LoRa 2015), it is indicated for new investments the use of LoRa instead of Mesh RF (FILHO; FILHO; MORELI, 2016). Besides, some authors in Sofia, Bulgaria (MATEEV; MARINOVA, 2018), were able to build prototypes with low-cost hardware, such as Arduino coupled to a shield with a LoRa transceiver, and monitor power meters. The gateway was made with a Dragino Gateway LG01, and it was possible to visualize on a web server the information obtained by the sensors.

In Ghent, Belgium (LAVEYNE; ZWAENEPOEL; EETVELDE, 2017), the temperature control in components related to power transmission lines could be done with the LoRa used an SX1276, component of commercial module RFM95. A thermostat connected to the analysis circuit of the Smart Grid changes values throughout the day and depending on the temperature, the current in the thermostat is changed. Therefore, it is possible to identify if this current value is within the established limits or not, and, finally, to trigger control elements. This service can add utility to smart cities (AL-TURJMAN, 2017).

Similarly, applications with smart meters for water and gas consumption could be carried out by different authors in Tamilnadu and Uttar Pradesh, India (MANOHARAN; RATHINASABAPATHY, 2018), (SALPEKAR; GUPTA; TEJAN, 2017). The goal was to place Microchip RN2483-based sensors with Atmega 328 in water meters to monitor consumption and pressure, temperature, flow rate, pH level, impurities, dissolved oxygen level and incidence of bacteria to communicate them with a Microchip gateway by LoRaWAN. In the worst case, the gateway can cover 2.5 km in range. At best, 4 km. It takes 16 gateways to cover the entire city operating with LoRa radio between -4 dBm and 20 dBm. This study may be complementary to the one conducted in Hualien County, Taiwan (LIU et al., 2018), where the authors were able to monitor the water quality in a lake using an ArduinoProMini sensor node for the gateway to communicate with a server via MQTT. The system, which is even equipped with a solar module for power supply, can be monitored in a web application.

Meylan, France, showed the use of LoRaWAN with electric energy meters implementing nodes and gateways in Paris and analyzing the maximum reaches. In all 19 gateways separated by 1 km of each other were positioned and, in this scenario, 17 km^2 were covered using 11 B packets. The authors stressed, however, that since LoRa can be adapted for use in urban environments, the duty cycle issue is purely legal and not an impossibility in transmission, so it may or may not be respected. It was also reported that latency is what determines good data communication and the sensitivity of the antenna varies according to the SF, with the minimum SF7 being -124 dBm and the maximum -137 dBm for SF12. Besides that, if 2 packets are received simultaneously by a gateway, each coming from a node with the same SF and same frequency, the highest power packet will be decoded if it has 6 dB higher than the other packet (VARSIER; SCHWOERER, 2017) (NAKUTIS et al., 2018).

4.1.3 Applications in Smart Farms

LoRa applications for Smart Farm are also typical. In Campinas, Brazil, precise rural coverage information was studied under different gateway positioning heights. A gateway-server communication system was used with LoRaWAN (gateway-node) and LTE (Long-Term Evolution (gateway-server)) to validate the best form of communication at certain distances in 2 specific cases: Air gateway (drones) on the move. The results showed that for a radius equal to 45 km and an air gateway height equal to 50 m, the gain of using these gateways is equal to 2 times the coverage than using a terrestrial solution (CARRILLO; SEKI, 2017).

Plantations can be monitored with LoRa, as verified in Torino, Italy (USMONOV; GREGORETTI, 2017). In rural areas, BLE and ZigBee networks have been implemented for monitoring, but these solutions have little reach. Cellular networks have greater range, but need solar panels to power the modules and also depend on the availability of the cellular system. Using a Ra-02 module (based on SX1278), which communicates with an Atmega328P, a PCB was prototyped for the sensor node and another PCB for the gateway node in order to transmit data packets from 9 B to 1000 nodes in the monitoring of these nodes in relation to the water consumption of an application with irrigation for plants by drip technique. The estimated battery life for this case is 2 years, and also, other authors have proven that it is possible to achieve a 7 km range with Risingf model RHF2S008 gateway and, as a node, a Risinghf USB modem RHF3M076 for analog applications (SILVA et al., 2018).

In Tronoh, Malaysia, a network of wireless sensors for monitoring environmental variables (temperature, humidity and oxygen level) in a factory operation of bird nests was constructed by some authors (IBRAHIM et al., 2018b) (IBRAHIM et al., 2018a). These nests, which are later processed to be used as cosmetics or health products, are monitored with a central gateway for external communication and several nodes strategically located in the environment. A mobile application was developed to assist in monitoring the entire process and analyze the times when birds enter the nests. Authors in Kuala Lumpur and Tronoh, still in Malaysia (IBRAHIM et al., 2018c), have created an IoT network to monitor mushroom greenhouses. In this case, humidity, carbon dioxide, and temperature sensors were used to monitor the greenhouses. The distance between the node and the gateway was not greater than 100 m, and it was found that applications for this type of remote sensing are required of a maximum of 20 B in the transmission packet. As a result, the data could be seen by a mobile application.

In Orissa, India (SAHOO; PATNAIK, 2017), a circuit capable of monitoring via LoRaWAN (used RF-LoRa-868) the amount of energy consumed by a solar panel. These data were then processed by an Atmega328 and stored on an SD card using the I2C and ICSP protocols so that data between the LoRa module and the monitoring circuit communicate by UART. A server is connected via the TCP/IP gateway.

Field animal monitoring is a task that until then required expensive electronics and consumed a lot of battery power. Studies in Montevideo, Uruguay (BELLINI; AMAUD, 2017) have proven that this task can be done with reduced investment and efficiency. Here an accelerometer (ADXL362) was used with an MSP430FR5969 processor and LoRa SX1276 transducer to monitor the temperature in farm animals. Each animal has a collar or ear tag with an accelerometer integrated with LoRa. The transmission system was optimized via FIFO to conserve battery life, and with this, 11.4 km of the range was achieved. The best ratio of transmission per battery usage was 1 transmission per hour. Thus, it is possible to estimate that the battery would last around 4.6 years. The total cost was less than $ 25 for 100 units of us. The authors also reported that the higher the bandwidth used, the longer the battery life tends to be.

Other work in the same segment, in Ioannina, Grevena and Kavala, Greece (ZINAS et al., 2017), a monitoring network for animals under LoRa transmission was developed by developing the nodes with Arduino SODAQ v2 and 2500 mAh of integrated power to a solar panel of 1 W (creating an autonomy of 35000 transmissions) and the 2 gateways with Raspberry Pi 3 and SX1273 IMST, which communicate with a database and an application server via MQTT broker. An Android application (CowTrack) has also been developed to monitor animals in real time once the sensor data has been obtained. The authors pointed out that the tracking of animals today is carried out by LTE and GPS networks (with consumption of 140 mA for transmission 2 or 3G, which has a maximum range of 80 to 100 km). Besides, it concludes that 1 gateway could sustain 20 to 30 nodes in this scenario.

Monitor activities of cows in fields such as the route that is made by the animal to feed and the health of this animal were studied in Baotou, China (LI; XIAO; LIU, 2018). For this purpose, an SX1278 was used in the node integrated with a microcontroller STM32L151. At the gateway, a Raspberry Pi and SX1301 to operate at 433 MHz and under transmission power to 18 dBm. The total amount of 200 packages were sent to evaluate the efficiency of the proposed system (1 package/30 s) and, as a result, for the maximum distance of 1.23 km, the receiving rate was 30%, while 100% was only possible at 500 m for an urban environment. For a rural environment in 2.25 km, it was possible to obtain 53% efficiency and 100% in 920 m.

Studies for applications that evaluate air temperature and humidity, leaf water content and soil moisture in a vineyard in Skopje, Macedonia, were also available (DAVCEV et al., 2018). In this scenario, a TTN connection with a server was used. In the sensor nodes were integrated data receivers (conventional sensors that quantify an environmental variable) and data modifiers (actuators). No hardware was reported, but the sensor node was located 1 km from the gateway to get as a bottom line some graphical reports containing the values of the measured variables.

Using drones with LoRaWAN to identify the incidence of forest fires and communicating in time was a study conducted in Ruse, Bulgaria. In this scenario, it was possible to use an IMST iC880A mounted on a Raspberry Pi next to a Pycom LoPy to connect 6000 sensor nodes through the forest at strategic points and with a history of fires that evaluates temperature, humidity, and atmospheric pressure. Thus, once detected at the sensor nodes some minimal indication of fire, bodies responsible for the management of natural disasters can be triggered (HRISTOV et al., 2018).

4.1.4 Applications in Health Care

Evaluate the performance of LoRa and LoRaWAN in cases of Health Care (HÄMÄLÄINEN; LI, 2017) has also been the target of some authors in Istanbul, Turkey and Rome, Italy (BUYUKAKKASLAR et al., 2017). It is possible to monitor people's quality of life, such as heart rate, respiration, blood fluid level, and others, using LoRa HopeRF RFM95/96 integrated transducers to Arduino in nodes and Raspberry Pi 3 with HopeRF RFM95 in the gateway, as well as integration with servers.

In the studies in Sfax, Tunisia and Marburg, Germany (MDHAFFAR A., 2017), LoRa was used to monitor patients who are in places far from health centers. There are already remote data routing studies for monitoring health-related conditions, but they all use mobile phone networks to communicate with servers. With Arduino in the nodes integrated to a Libelium (Cooking Hacks Group) and Raspberry Pi in the gateway, 3 dBi gain antennas and 2200 mAh battery (under 10 days, sending 1 packet per min), a 33 km^2 were reached. LoRa is efficient for monitoring duty cycle data or for continuous detection of time data. In ECGs, this technology may not be the most appropriate unless hybrid technology is created with those that support real-time monitoring.

Physical conditions of athletes can be monitored via LoRa. In Belgrade, Serbia and Ljubljana, Slovenia (KOS; MILUTINOVIC; UMEK, 2017), it was verified the implementation of remote sensing to monitor the health of athletes employing the of several sensors in the body of the athletes, which are sent to a database, and then analyzed. The transmission between the sensors and the gateways can be made by adjusting the LoRaWAN under transmission power of 1.5 to 100 mW. According to the authors, it is not possible to define a better method of wireless transmission for this type of application considering the forecast needs, but the most appropriate technology is the IEEE 802.11ah that achieves 40 Mbit/s and 1 km in scope.

4.1.5 Location applications

There are LoRa applications that evaluate the replacement of GPS tracking by LoRa in certain activities. This study became relevant since many applications use GPS as a way to track people, animals, and objects, but they consume much energy (30-50 mA while the LoRa consumes on 2.8 mA, 38.9 mA transmitting and 14.2 mA receiving for 868 MHz). In this study, in Kongens Lyngby, Denmark (FARGAS; PETERSEN, 2017), used a Waspmote (Atmel ATmega1281) and 4 gateways (Kerlink) synchronized with The Things Network. Each node was separated by 5 km from the nearest gateway for the transmission power of 14 dBm. It was possible to create an algorithm via LoRa with GPS efficiency and accuracy of 100 m for static cases. For moving cases, it is possible to report only approximations and the battery consumption found was 12.9 mA. The authors also observed that this result is very positive given the fact that a network consisting of GPS and GSM consumes 400 to 600 mA, given this also proven in the study in Mons and Gembloux, Belgium, Rabat, Morocco and Algiers, Algeria (DEBAUCHE et al., 2018), in which LoRa was able to assist in the remote monitoring of hives.

Studies conducted in Stekene and Ghent, Belgium (PODEVIJN et al., 2018), have shown that LoRa can also be used for geolocation and screening of materials in warehouses, with tests made for 6 nodes (sending 2 B packets, sufficient for the data of a sensor and the amount of battery) that were moved from place to place. It was possible to perform the screening with different SF and with an error smaller than 500 m. The authors pointed out that geolocation by LoRa is not as efficient as GPS, but consumes much less of battery and can be used for both location and communication.

4.1.6 Application in universities

In the Scientific Campus of the University of Lille, France (LORIOT; ALJER; SHAHROUR, 2017), some authors sought to transit the campus with a vehicle to qualify the signal during broadcasts. As a node, was used a Raspberry Pi and a Libelium LoRaWan and for the gateway, a Kerlink Wirnet module. The connection between gateway and server was made via a 4G network and, in this way, a 1.2 km range was obtained, showing a more general application study but of utility for university areas or similar.

In Chiayi, Taiwan (KE; LIANG; ZENG, 2017), with ARM M0, Nano100LE3BN, SX1278, using a 70 cm and 3 dBi antenna for gateway and at the nodes a 2 cm antenna and 0.7 dBi, a LoRa network with Mesh topology was developed for application in a Taiwanese university campus. The rates of receiving packets using Mesh networks proved to be quite capable. As an example, in a node located 800 m from the gateway, there was no data reception between gateway-node, with jumps between 3 nodes up to gateway, it was possible to reach 94.94% of reception.

4.1.7 Application in industries

In Industry 4.0, also known as Cyber-physical Systems (CPS) and Industrial IoT (IIoT), in Brescia, Italy, and Sundsvall, Sweden (RIZZI; FERRARI; FLAMMINI, 2017) it was sought to employ the LoRa with an SX1272 and STM32 in the nodes and a Multitech with SX1301 for the gateway. A LoRa system was implemented for 6000 nodes in an industrial model, evaluating how feasibility focuses. 1000 packets with 50 B per packet were transmitted, and it was concluded that LoRaWAN has the potential to replace traditional transmission methods in industries, especially in cases where the time between transmission is on the order of 1 minute (tested for a distance of 5 m between node and gateway). Currently, industry-applied solutions are limited to the use of WirelessHART and ISA100.11a which are based on IEEE802.15.4 and require specialized gateways for connection to the internet, which suggests that the use of 3/4/5G networks seem to be more attractive; however, these were not created for deterministic real-time sensing cases. In the industrial segment or any other, for integration with a database and real-time data sampling, one of the most used communication protocols is Message Queuing Telemetry Transport (MQTT) (BONAVOLONTA; TEDESCO; MORIELLO, 2017).

The work carried out in Plovdiv, Bulgaria, (PENKOV; TANEVA; KALKOV, 2017), validated through comparison between the existing network protocols according to reach and data rate, the operation of LoRa with MQTT. The MQTT came intending to create an efficient protocol for transferring data from devices with limited hardware resources. With scalability of 1000 knots per gateway, integrity with The Things Network and following EIRP and duty cycle limitations (ETSI), LoRa and MQTT join together for easy maintenance, low cost, low power consumption, reliability and security, secure Internet connection and long lifecycle.

4.1.8 Military applications and signal interference

From interference with other signals, however, in Moscow, Russia, and Almaty, Kazakhstan (TIKHVINSKIY; KORCHAGIN; BOCHECHKA, 2017) the impact of a LoRa transmission on aircraft radars and other devices in the 800 MHz band used in Eastern Europe has been studied. For this, radars and spectrum analyzers were used according to ITU-R M.1830: DRL-6 (8) or DRL-7 (10). It was concluded that the use of the band studied is attractive from the use with LoRa because it is free and does not bring regulatory barriers, but it brings some complications because this band is already occupied by radar equipment in airports, proving the interference without intentions.

In Karachi, Pakistan, some authors have developed an embedded system to allocate in military outfits that are capable of evaluating soldiers' health variables and sending data through LoRaWAN to a central data center. For that, an ARM microcontroller with an ESP32 integrated to the LoRa transceiver and its sensors were used (ARSALAN et al., 2018).

Still in the military context, in Bangkok, Thailand (SAN-URN et al., 2017), a LoRa communication system for troop tracking was created, developing hardware for both node and gateway (located 500 m from the ground and with a 4 dBi antenna). At the node, an Arduino was integrated with a LoRa module and Li-ion battery TP4056 with a module of 3.7V. In the gateway, a Raspberry Pi with an AC/DC source of 12V and 2A next to a regulator of a tension of 5V. Communication between gateway and internet is performed via UDP while both node and gateway communicate with respective LoRa modules via SPI. Under a study of distance concerning noise and sensitivity, it was obtained 0.5 km range, and a node could be connected to up to 10 different sensor types. Similarly, in Maryland, USA (JALAIAN et al., 2018), some authors used the Pycom, Pytrack and mDot LoRaWAN boards of Multitech as sensors, the latter being a module also used in conjunction with an Arduino Leonardo and xBee shield as a gateway programmed with the aid of Node RED. The maximum range achieved was 9.8 km in these configurations, mainly due to terrain restrictions (mountains).

4.2 What are the main challenges that LoRa faces today?

Based on the information obtained from the articles, it can be stated that for LoRa applications, the interference that the transmission via LoRaWAN may cause in other signals is a point that deserves attention (TIKHVINSKIY; KORCHAGIN; BOCHECHKA, 2017) (GEETHA; GOUTHAMI, 2017). It should be noted, however, that this finding was obtained at a specific frequency in the European scenario and does not necessarily represent interference in all other scenarios. In Brazil, for example, since LoRa operates at 915 MHz, the same types of situations shown by the authors are not relevant. In any case, interference tolerance is a challenge not only for LoRa but for any type of wireless transmission.

It has also been verified (MDHAFFAR A., 2017) (KOS; MILUTINOVIC; UMEK, 2017) that continuous time data sensing (as in ECG, EEG or athlete monitoring), LoRa technology may not be the most indicated. The authors' results, in this type of application, showed that the data rate for LoRa may not be sufficient. It is also noticed that there are still few studies carried out in Brazil or by Brazilians, justifying that the development of LoRa technology in the national territory lacks advances in the area and practical implementations in real remote monitoring environments, which can be achieved after all regulations of this type of wireless transmission. Therefore, duty cycle and transfer rate are the ideal performance limiters to adhere to LoRa as the best technology for remote sensing and IoT, so that the integration of LoRa reach with the data rate of cellular networks would be a challenge whose results would bring numerous benefits (PARK; HWANG; KIM, 2017).

The studies presented in Salvador, Brazil (OLIVEIRA; CONCEIÇÃO; NETO, 2018b), evidenced the use of LoRa in several applications under a systematic review of the literature, which also contemplates part of this study. It was possible to quantify the usability of LoRa in diverse applications and with low cost hardware, although several secondary works use high performance equipment and optimized for the utility in which it is applied. It was also possible to identify that there are still few cases where LoRa was not suitable for remote sensing, which supports the thesis that the technology is suitable for integration with the Internet of Things and its requisitions.

Chapter 5

Empirical Results

This chapter will show the tests performed with low-cost setups that meet the needs of prototyped remote sensing. To do so, 2 types of setup have been created and will be described in more detail in the following sections.

5.1 Objectives of the experimental analysis

The objectives of the tests were to identify the range that LoRa obtains using the frequency of Brazilian operation. According to the systematic review of the literature, these conditions have not yet been explored. Prototyping was a determining factor for the development of a library configured for the restrictions imposed by Anatel and that allows the public use of the concepts obtained by the tests, to contribute with the scientific and technological society to the LoRa technology and its dependencies.

5.2 Setup 1: Dragino

The first tests performed for LoRa validation were made for sensor nodes with Dragino v1.4 (DRAGINO, 2018) hardware, which is a shield based on the LoRa SX1276/SX1278 chip, with 168 dB maximum link budget, +20 dBm RF output, sensitivity of -148 dBm, transmission current of 10.3 mA and 200 nA in sleep mode, possibility of modulation FSK, GFSK, MSK, GMSK, LoRaTM and OOK and packet engine up to 256 bytes with CRC.

For the parameterization of the tests performed in Dragino to be processed, an Arduino UNO Rev3 (ARDUINO, 2018), which uses an ATmega328P microcontroller, is used and the technical specifications are 32 KB Flash memory, 2 KB SRAM, 1 KB EEPROM, a clock rate of 16 MHz and 20 mA of current consumption.

The gateway was prototyped with a Raspberry Pi Model 3 (RPi) which uses a 1.2 GHz ARM Cortex-A53 quad-core, 1GB RAM, Wi-Fi connection, 100 Base Ethernet, Bluetooth Low Energy (BLE), HDMI, 4 USB ports, camera portability, stereo output, and other features. This gateway was also connected to a Dragino module for receiving packets and communicating with cloud servers, as shown in Figure 5.1 with a temperature sensor, photoresistor, magnetic, rain detector, humidity, gas, infrared and DHT.

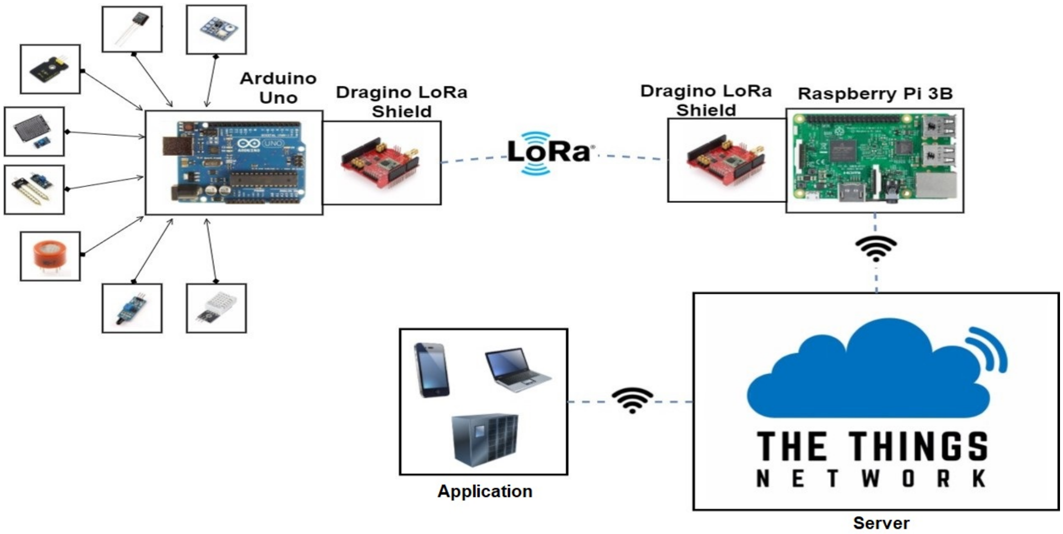


Figure 5.1: Prototyping scheme with Dragino, Arduino and RPi.

Dragino, Arduino and RPi were chosen because of the low cost and accessible programming in C, as well as the availability of tests for operation at 915 MHz.

The tests performed below were published on the website specialized in embedded systems, Embarcados.com (OLIVEIRA, 2018) and were carried out in the urban area of São José dos Campos, in the interior of São Paulo, between May and July 2018.

5.2.1 Physical setup

As described, the development for prototyping consisted in integrating the Dragino shield with the sensor node module, responsible for the capture of environmental data (in this case an Arduino with a temperature sensor LM35) and also with a gateway node assembled with another Dragino shield and a RPi. The list of materials used in these tests is described in Table 5.1 and Table 5.2 shows the necessary information of the Dragino setup, while the configuration step-by-step follow Figure 5.2.

The designation of the connector pins was made according to Table 5.3.

In Figure 5.2, the arrows in blue do not include the pinout of the RPi, but the diagram

Table 5.1: Pinout for gateway

Item	Qty.
Dragino	2
Raspberry Pi 3B	1
Arduino UNO	1
Jumpers	20
HDMI cable	1
Monitor	1
Keyboard	1
Mouse	1
Power supply	1
USB cable	1
Sensor LM35	1

Table 5.2: Basic settings of the Dragino setup.

Item	Dragino	Arduino	Raspberry Pi
Chip	SX1276/SX1278	ATmega328P	ARM Cortex-A53
Frequency	915 MHz	N/A	N/A
Power supply	N/A (Shield)	USB/9-12V	5V 2A
Device dimension	62x43x23 mm	69x53x15 mm	86x57x15 mm
Device weight	22 g	25 g	45 g
Local range temperature	25-30 °C	25-30 °C	25-30 °C

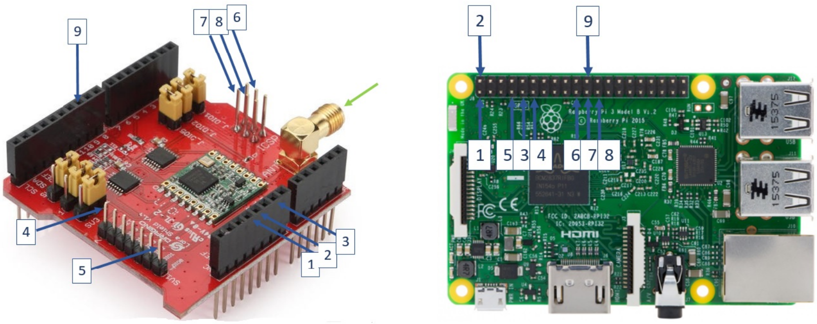


Figure 5.2: Connecting the shild Dragino and RPi.

as assembled the connection in the Dragino. The correct pinout is described in Table 5.3 by the column named “Pin RPi”. After the connections, the antenna at the location indicated by the purple arrow was inserted. The feasibility of using this antenna is a parallel study that can be reviewed in the future.

In the RPi, a keyboard and a mouse were connected via USB, as well as an HDMI cable to a monitor for data sampling. There is the possibility of the connection wired by the LAN network or the configuration of the RPi to use the Wi-Fi. In this case, the

Table 5.3: Pinout for gateway

Map	Dragino	RPi	RPi pin
1	3V3	3.3V PWR	1
2	5V	5V	2
3	GND	GND	9
4	RESET	GPIO17	11
5	DIO0	GPIO4	7
6	ICSP4	GPIO10 (MOSI)	19
7	ICSP1	GPIO9 (MISO)	21
8	ICSP3	GPIO11 (CLK)	23
9	D10	GPIO25	22

Wi-Fi was used.

The final prototype can be seen in Figure 5.3, containing the LM35 temperature sensor, sensor node with Arduino and Dragino and gateway with Raspberry Pi and Dragino.

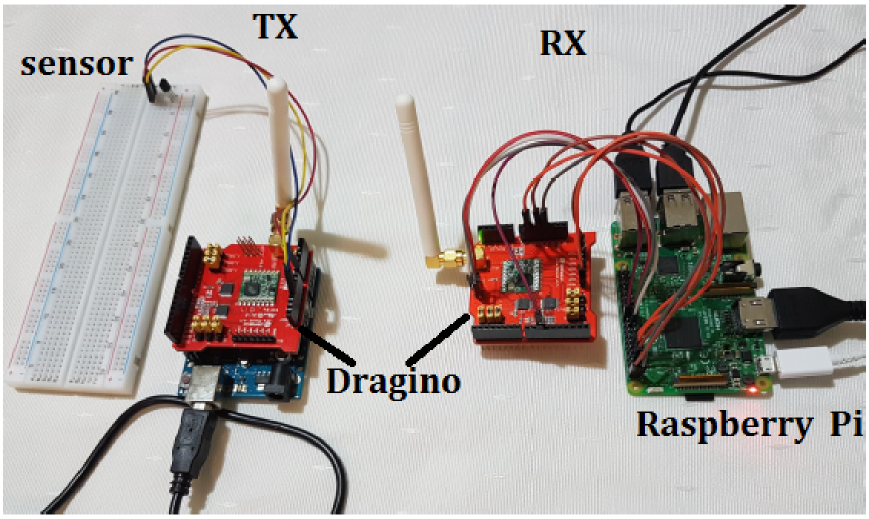


Figure 5.3: Dragino Modules with Arduino and RPi.

In Appendix F and Appendix G it is possible to check the node and gateway settings in more detail.

5.3 Setup 2: ESP32 LoRa

The tests carried out with Heltec's ESP32 LoRa modules (HELTEC, 2018), another low cost module, are in the process of acquiring experimental data. This hardware, unlike Dragino, already has a processor (Tensilica LX6 and ULP 240MHz) integrated with the LoRa SX1276/SX1278 transducers, in addition to the sensitivity of -139dbm and Wi-Fi connection.

Figure 5.4 shows the connection of the parts between the LoRa ESP32 modules, which is greatly simplified compared to the Dragino setup.

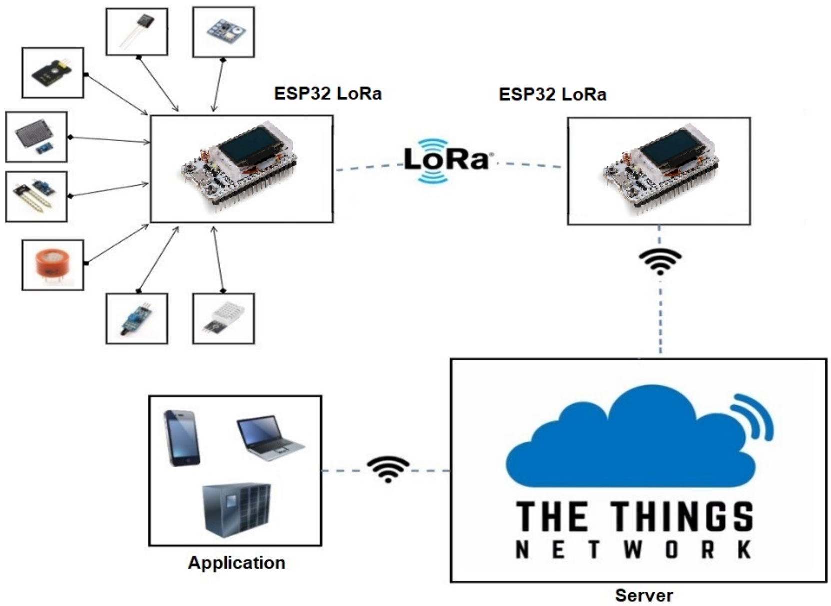


Figure 5.4: Prototyping scheme with ESP32 LoRa.

Part of the sensor node code is in Appendix B and the Gateway in Appendix C.

The setup designed for testing with the Heltec modules can be checked in Figure 5.5.

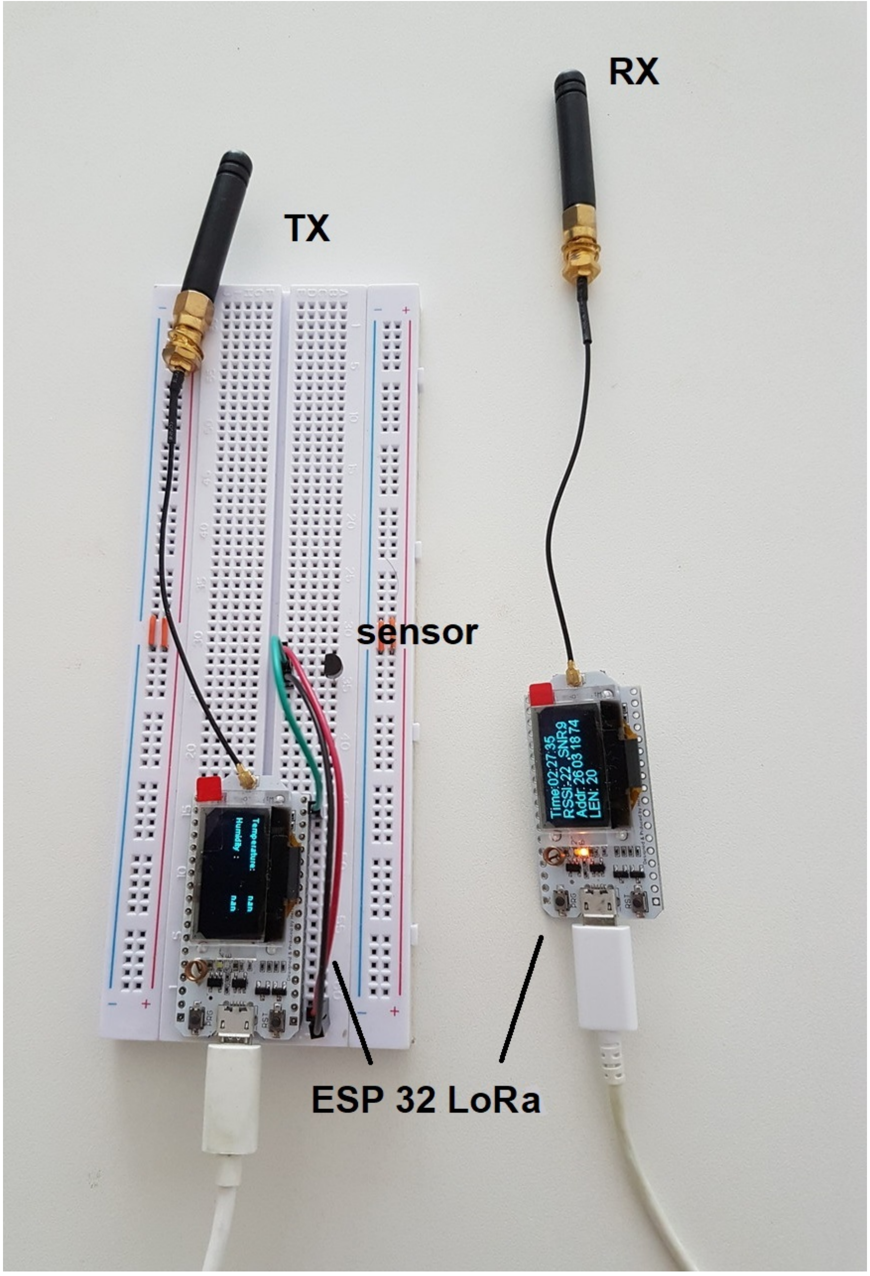


Figure 5.5: ESP32 LoRa Modules.

These modules were selected for easy prototyping and simplicity in testing, so the hardware is preconfigured from the factory for use with LoRa, and does not require additional hardware such as Arduino or Raspberry, resulting in greater project investment savings. The antennas used, LM35 temperature sensor, jumpers, and USB cabling are identical to the setup mounted with Dragino.

Figure 5.6 shows the only connection to be made to both ESP32 LoRa modules for running the tests. The antennas are built-in and the computer does all man-machine communication with a development interface, which in this case was used the Arduino's IDE, so no additional port configuration or serial communication enable for the ESP32 setup LoRa.

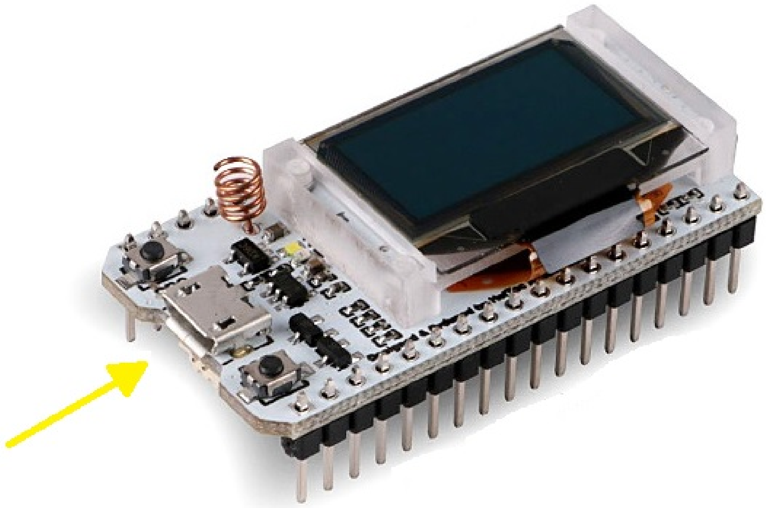


Figure 5.6: Conexão dos módulos ESP32 LoRa.

5.3.1 Results with ESP32 LoRa

The initial tests with ESP32 LoRa were performed from the hardware validation optics, for now, which means that it was possible to qualify the packet transfer for a distance between the 2 m sensors using SF 7 and considering the parameters of Table 5.4.

It is worth mentioning that the choice of this methodology was based on the prioritization of theoretical papers in the submission of articles for scientific journals and presentation at congresses (OLIVEIRA; CONCEIÇÃO; NETO, 2018b).

Table 5.4: Basic settings for ESP32 LoRa setup.

SF	7
LoRachip	SX1276
Frequency	915 MHz
Power supply	5V 2A
Device dimension	50x26x10mm
Device weight	13 g
Local range temperature	25-30 °C

5.3.1.1 Test plan

In order to finalize the test battery with the ESP32 LoRa modules, it is intended to perform the same type of experimental environment made with the Dragino setup, that is, to introduce the modules to a real application environment and remote sensing capable of monitoring environmental conditions such as temperature and humidity, in addition to providing the received signal strength indicator (RSSI), which will be able to show the potential of LoRa for later identification of the signal-to-noise ratio (SNR) and to quantify the efficiency of the setup.

With such data, some of the topics of interest to be studied are also the impact of the reach and the capacity of byte transmission in relation to RSSI, as well as the autonomy of energy by varying the size of these packets and the transmitting antenna. All these considerations will be optimally considered based on the results of the tests in the specific library for the Brazilian operation.

5.4 Cloud server configuration

The Things Network (TTN) is an Internet database of Things that has existed since 2015 and started in Amsterdam, The Netherlands. With TTN, it is possible to send remote sensing data that has been received by a gateway configured with one of the platform servers and then to use such data for statistical analysis or creation of equipment performance reports (TTN, 2017). The advantage of using this cloud platform lies in the fact that it is already customized to receive LoRa data, which makes it quite versatile, saves planning time and makes project costs cheaper since it is not necessary the creation of another standardized server that would perform the same functions as the TTN.

To configure this server that will sample incoming packets, the following steps must be considered. It is important to note that the TTN does not do any actuation of response, but can be associated with some actuator in other applications capable of doing so, like Cayenne IoT, Grafana or Google Data Studio. First, it is necessary to access the platform (thethingsnetwork.org) and make a registration and login, according to Figure 5.7.

In the initial screen, 2 tabs are shown that need to be adjusted: Applications and Gateways, according to Figure 5.8.

In Gateways, the RPi was registered with the Dragino module to make it integrated into the server. Some necessary information such as gateway name, region, and frequency of operation have been configured according to the RPi identifier programmed previously, according to Figure 5.9.

Similarly, as shown in Figures 5.10 and 5.11, in Applications, the nodes that make

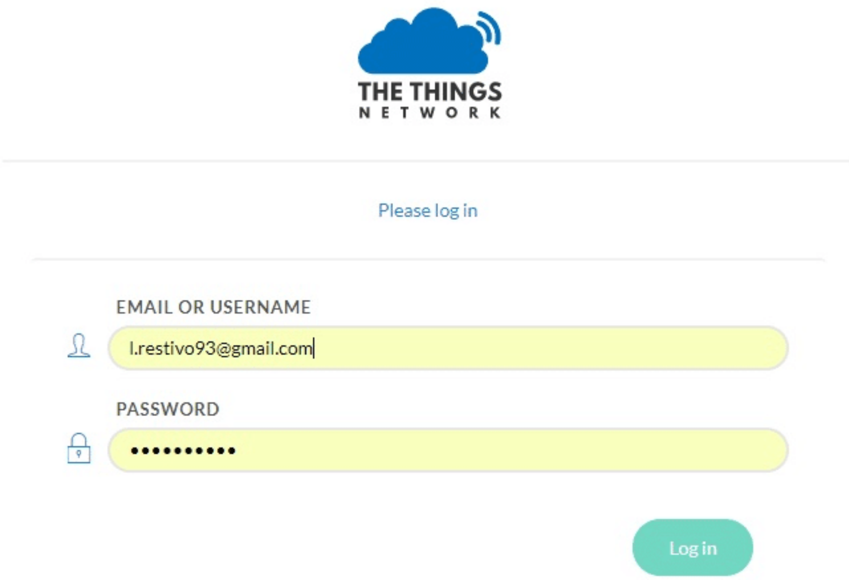


Figure 5.7: Register on The Things Network platform.

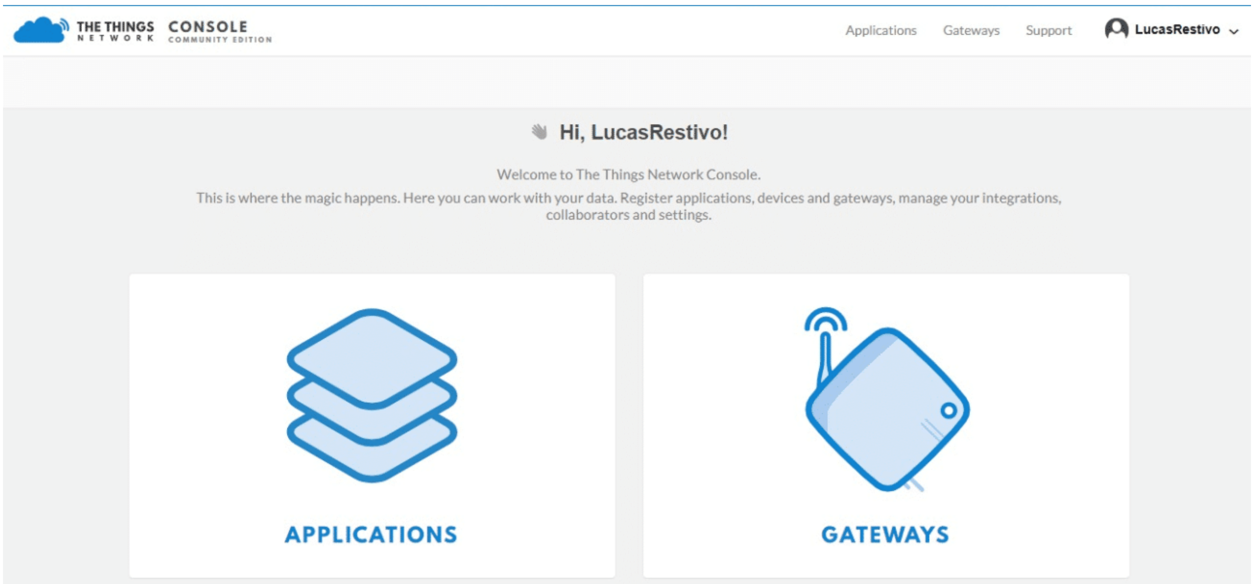


Figure 5.8: The Things Network platform home screen.

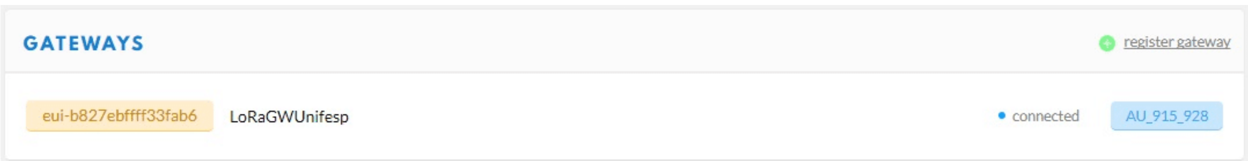


Figure 5.9: Register for gateway on The Things Network platform.

up the entire system are registered, so that each has a unique record and is linked to its respective code source on Arduino. This registry consists of 3 keys generated by the server: Device Address, Network Session Key, and App Session Key.

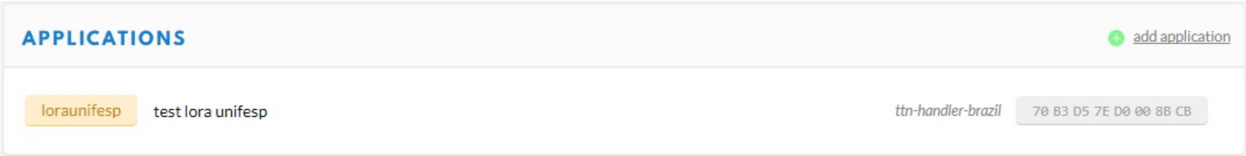


Figure 5.10: Application registration on The Things Network platform.

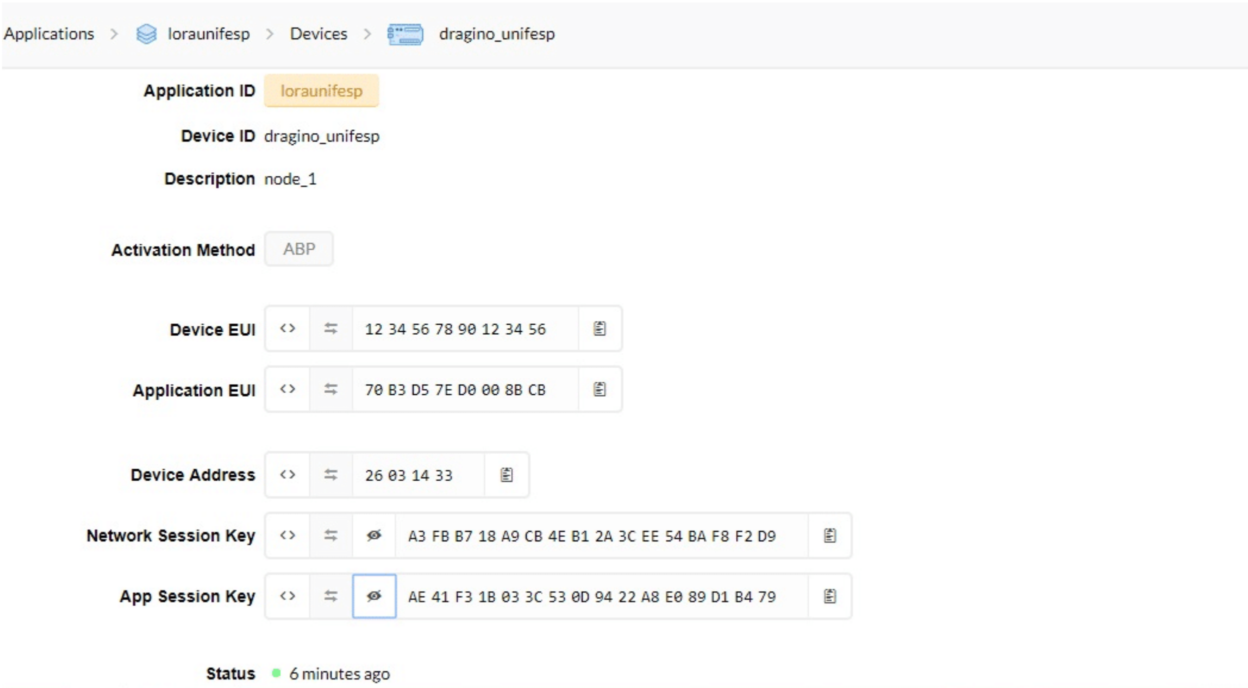


Figure 5.11: Device registration on The Things Network platform.

The received, sent packets and their respective transmission details could be queried on the Traffic tabs on the server. The duration of time in the air that a packet took to be sent from a sensor node to a gateway, the operating frequency that this system is operating, the coding rate (CR), spreading factor, bandwidth, node identifier, and package sizes are variables seen in the management tabs of the server.

It was also possible to view the transmission details of each packet that was received by the gateway, as in Figure 5.12 and 5.13. In this test, a sensor node of the Applications tab was created and a device address that was described in the Arduino code. As an example, the full-number counter 43 identifies an encoded load that has been sent from one node sensor with registration number *26031433* to the gateway *eui-b827ebffff33fab6*, which is the gateway created and exemplified by Figure F.11.

In the data traffic analysis, the tab containing the gateway information can show the node in which the respective packet is sent, the total size of the load and the HEX encoding of the information, as shown in Figure 5.14.

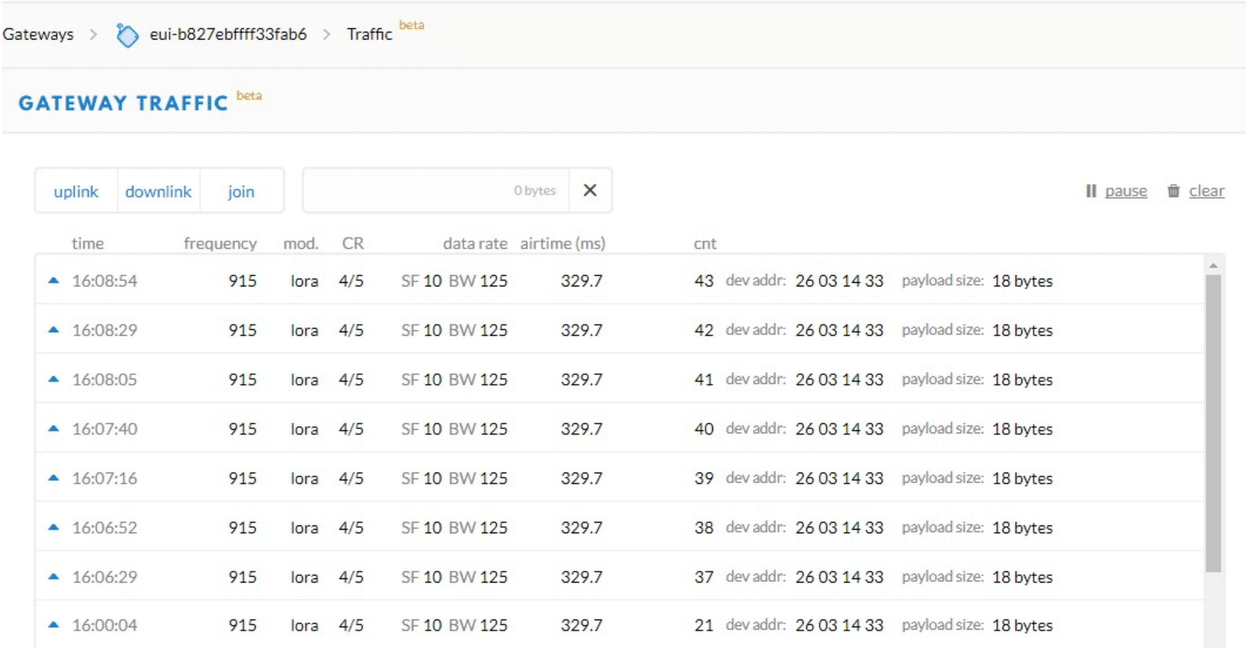


Figure 5.12: Data traffic on The Things Network platform.

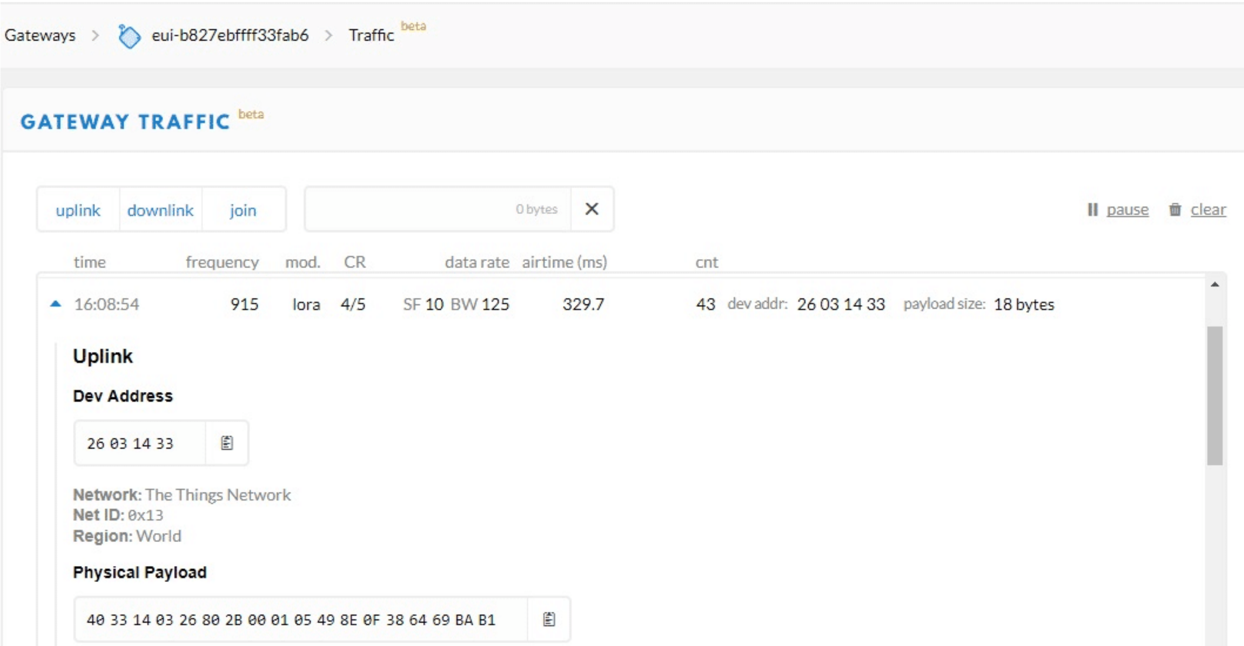


Figure 5.13: Final data on The Things Network platform.

In the data screen of the RPi, it could be noted that the encrypted data for the transmissions corresponds to the data received on the server. In the cited example of transmission 43, the packet data is recorded as sent, according to Figure 5.15.

It is also noted that in the Arduino Serial Monitor, the data obtained by the sensor is informed and queued for the wireless transmission together with a counting number for the quantitative analysis of the packages being sent, as well as other control information.

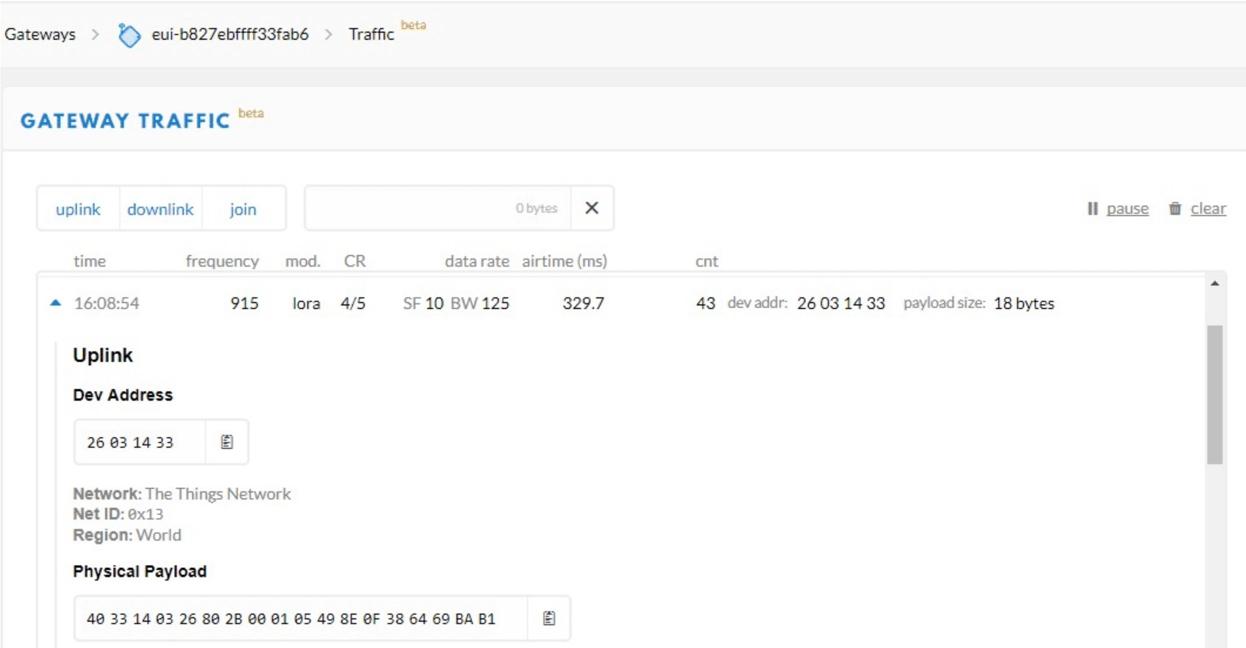


Figure 5.14: Data Flow on The Things Network Platform.

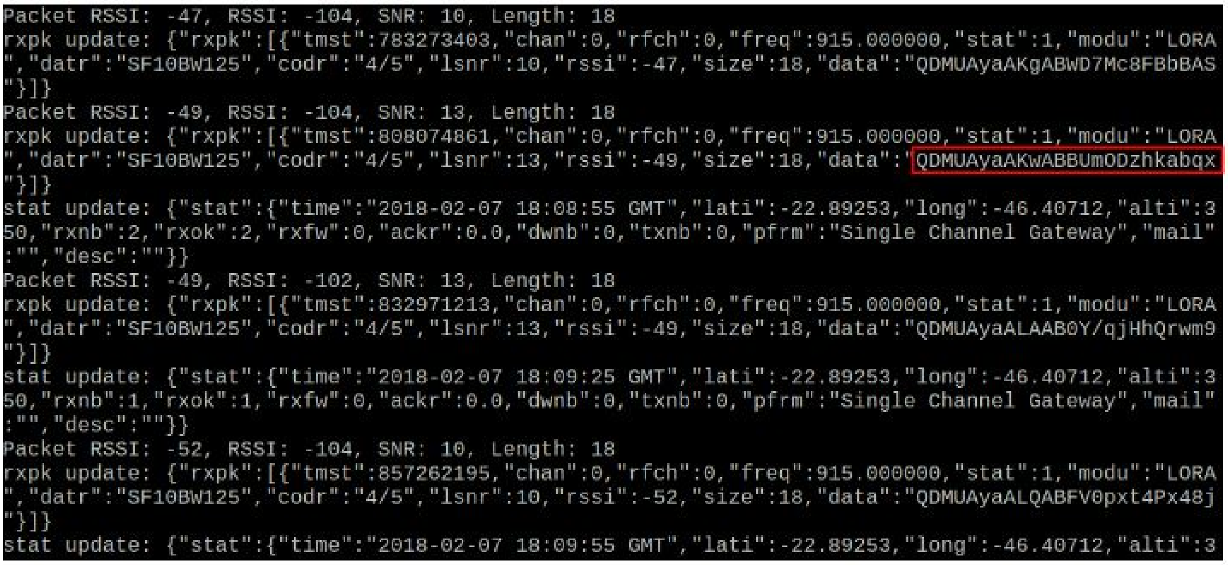


Figure 5.15: Data flow in RPi.

In the packet sampling screen received from The Things Network server, it is verifiable the correct data transfer by converting the DEC values of the sensors to HEX as shown by the server.

It is possible to verify the reduction of the time in the air that a packet transmitted with spreading factor 7 suffers concerning the same packet transmitted with spreading factor 10, according to Figure 5.17. The distance at which the tests were performed would not suffer a significant consequence of packet loss even with a higher spreading factor, however, if the same test is performed for more considerable distances between

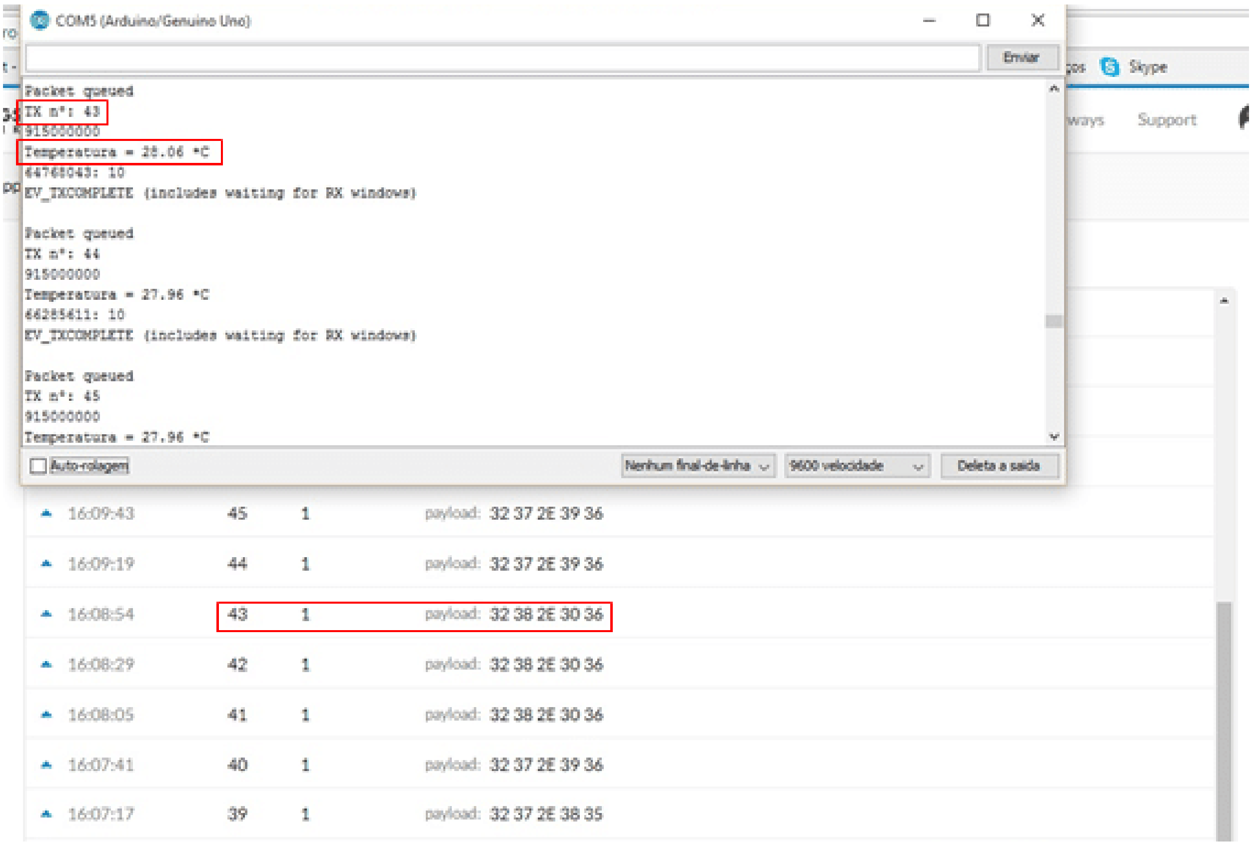


Figure 5.16: Arduino data flow.

the sensor node and the gateway (more than ten kilometers, for example), it is possible to notice differentiations in terms of losses of packets. This characteristic is intrinsic to LoRa technology and is because there is an inverse proportionality between the spreading factor and reach or time in the air, leaving standard all other parameters.

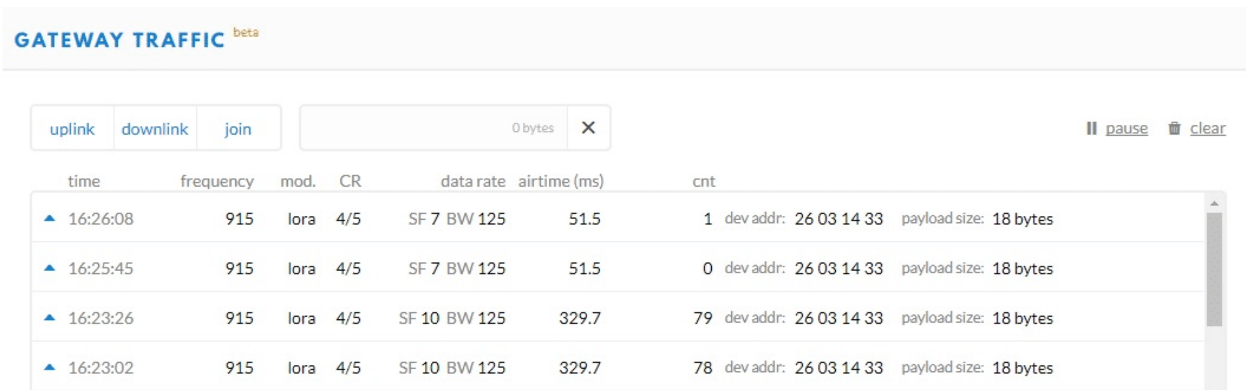


Figure 5.17: Data traffic for different spreading factors.

5.5 Results with Dragino

The methodology of the tests consisted in making a battery of practical tests for each possible configuration of SF and its respective distance between the sensor node and the gateway, allowing the statistical and staggered modeling for all the values of hardware. The test assumptions were the same for all SF changes, that is, the bandwidth used in all scenarios was 125 kHz and 18 B payload with the Dragino antenna power of 20 dBm. The results of the tests were then compared with the values identified in the LoRa transmission simulator developed by Semtech to quantify the transmission battery consumption and respective energy efficiency. For the acquisition of data sampling, 5 test batches were performed, and in each battery, 100 packets were transmitted by the sensor node containing the ambient temperature. Packages that could be viewed on The Things Network platform were counted as successful transmissions, while all lost packets were discarded. Thus, the average performance among these 5 batches constitutes the final use of the test.

Table 5.5: Reach Tests

Distance (m)	SF7 (%)	SF8 (%)	SF9 (%)	SF10(%)	SF11(%)	SF12(%)
2	99,8	99,8	99,7	99,8	100,0	99,8
500	96,4	99,2	98,0	94,5	94,2	93,8
1000	81,3	86,9	88,1	80,0	83,3	86,6
1500	54,5	62,9	72,3	62,8	71,1	79,4
2000	16	27,2	50,6	42,9	57,5	72,2
2500	0	0	23,1	20,2	42,6	65,0
3000	0	0	0	0	28,9	57,8

As Table 5.5 shows, packet transfer rate to different values of SF allows remote monitoring in various applications, such as a number of vehicles, air pollution, pedestrian flow, and waste management, for example. This is due to the high rate of receipt of packages for values up to 500 m, which is enough for some of the applications mentioned. As noted, for longer distances, transmissions are more likely to be successful if performed with larger SF, which directly impacts on energy consumption and in the time the package stays in the air.

Figure 5.18 shows the characteristics of the LoRa transmission to SF 7, containing the air time according to the practical samplings seen in The Things Network. For this configuration, power consumption, battery usage estimation, and other transmission information can be analyzed by Figure 5.19. The air-pack lifetime was 51.5 ms.

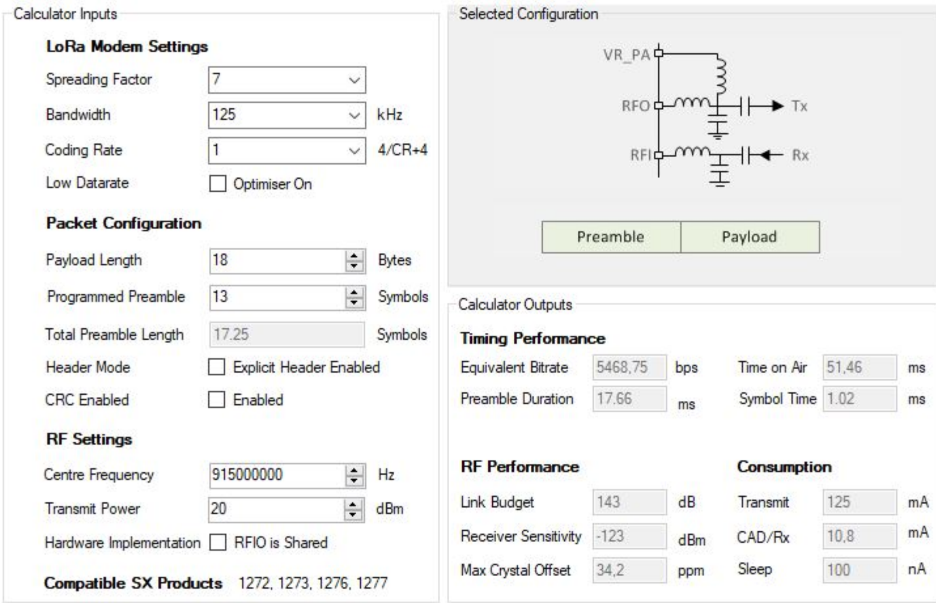


Figure 5.18: Simulated Sampling of LoRa in SF 7.

Under these conditions and using the indicated temperature sensor, the forecast for the use of a 3.3 V and 1000 mAh battery is 4605.56 days or approximately 13 years.

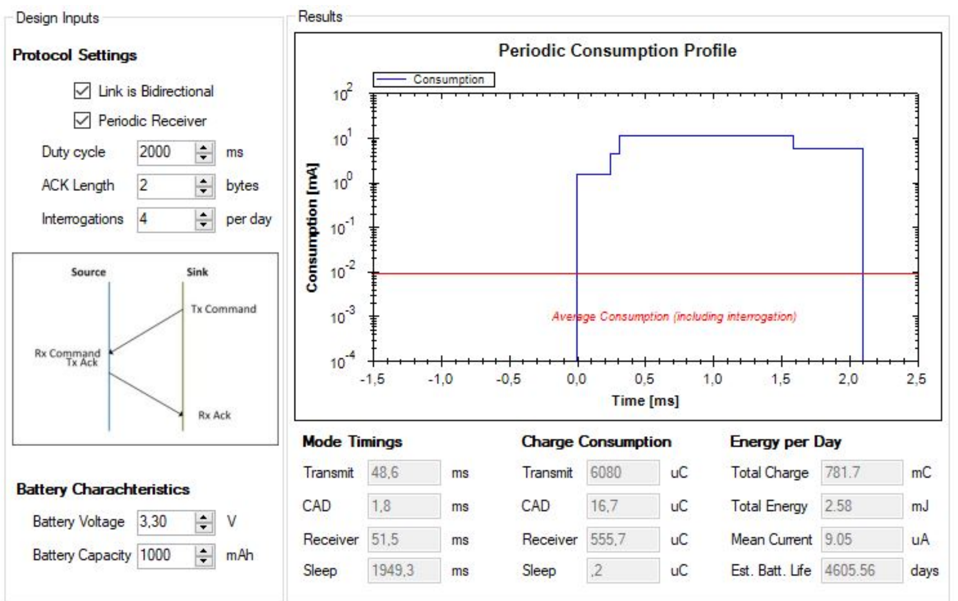


Figure 5.19: Simulation of LoRa in SF 7 - energy consumption.

The Table 5.6 shows the values of the duration time of the packets in the air (ms), average current consumption (μA) and estimated battery lifetime (days) considering all SF.

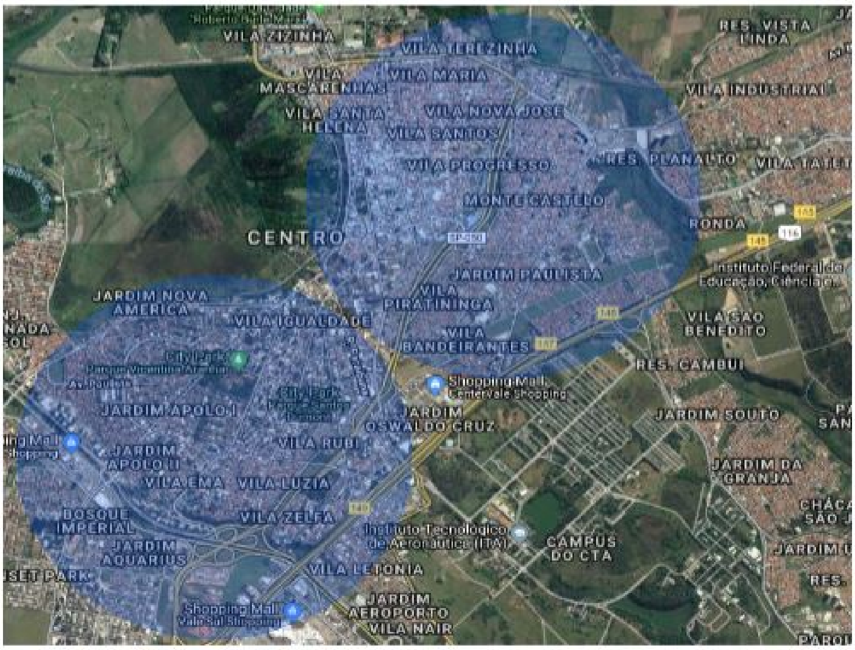
In Figure 5.20(a) it is possible to exemplify the coverage of 1.5 km radius when using 2

Table 5.6: General features

SF	Time on Air	Mean Current	Est. Batt. Life
7	49.4	8.81	11109.87
8	88.6	16.20	6032.88
9	177.1	31.45	3110.99
10	313.3	62.68	1560.75
11	626.7	126.84	771.32
12	1089.6	258.43	378.57

gateways receiving data from LoRa nodes spread in the city of São José dos Campos, São Paulo. It can be seen that several neighborhoods can be covered with this configuration.

In Figure 5.20(b) the efficiency of a single LoRa gateway is shown if this technology is applied to small towns even with the prototyping configurations exercised in this article. It is possible to observe that, despite the wide coverage that is reached, some practical restrictions are imposed by the environment itself, such as mountain obstacles of different sizes and intensity of local vegetation.



(a) According to tests.

(b) For a small town.

Figure 5.20: Coverage map.

Chapter 6

LoBRa: IoT in Brazil

The validation tests of the LoRa technology with Dragino and ESP32 prototypes were concluded using free libraries provided by the manufacturers themselves, which allows the configuration for SF 7 to 12 only in European or different frequencies of 915 MHz. In these libraries, the specifications allow SF values to be changed when using 915 MHz but with application restrictions, which means that in practical terms it is not possible to use this library with SF 11 and 12 with 915 MHz.

What was delivered as a final product is the LMIC library edited for Brazilian operations applications, that is, optimized for the application of 915 MHz and reusable in the Dragino and ESP32 LoRa modules, for example, allowing easy programming, practicality in equipment development and no configurations at the root of the base code platforms. The name given to this library was LoBRa. In this way, other professionals who wish to use LoRa technology in Brazilian characteristics and under a relatively low initial investment can use this library through a common development interface.

Thus, LoBRa, the custom library for applications in Brazil, will be able to contemplate the modules of the Dragino setup as well as the ESP32 LoRa setup because the setups do not differ considerably from the operation requests and in both sensor nodes the programming has the same architecture.

All project code are tested and available on Github for free public use and is available at ⟨https://github.com/LucasRestivo/LoBRa\⟩ (OLIVEIRA, 2019a), containing all specifications for Brazilian operation and restrictions of use following Anatel standards.

The first step in using LoBRa is to access the Github link containing the source code of the library and clone all content to the computer, as shown in Figure 6.1.

The set of files *dragino_esp32_libs* contains all the operating assumptions developed for the code of the nodes and gateways to operate independently of the chosen hard-

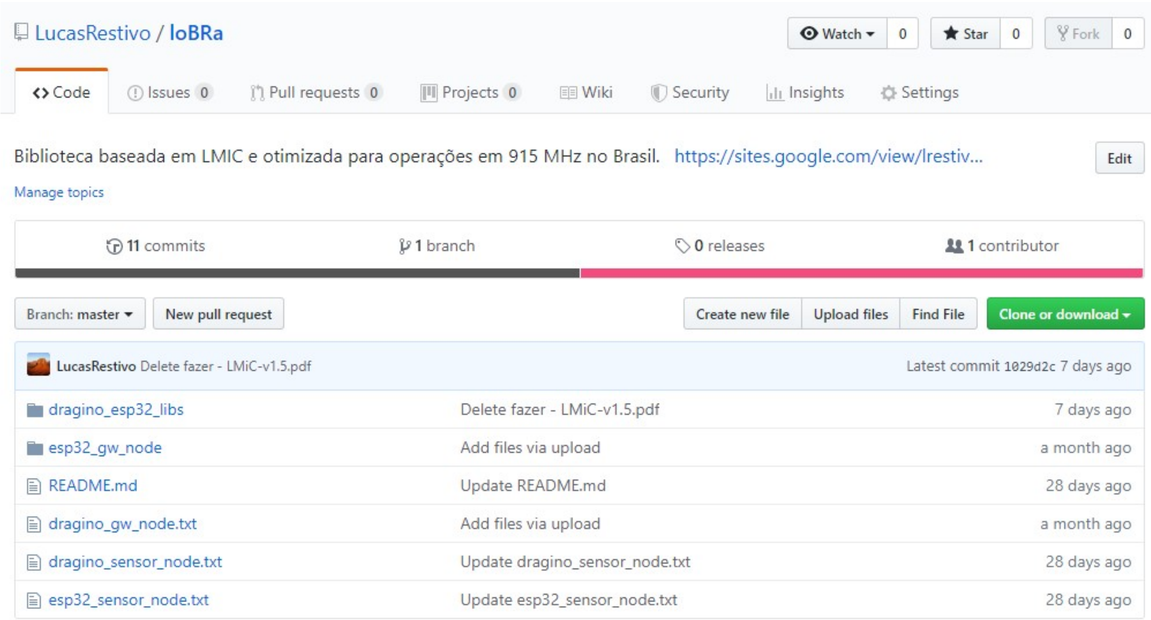


Figure 6.1: Github repository containing the LoBRa code.

ware. In other words, this file is LoBRa. The set of files that are contained in the *esp32_gw_node* folder contains the gateway codes for the ESP32 hardware. All files contained must be opened in the IDE and compiled simultaneously. The *README.md* file has the necessary configuration instructions, in Portuguese, that are set in LoBRa. The file *dragino_gw_node.txt* is the code corresponding to the gateway in the setup with Dragino, which in this case is used in a Raspberry Pi. The files *dragino_sensor_node.txt* and *esp32_sensor_node.txt* are respectively the code of the sensor nodes for the setup with Dragino and the setup with ESP32, both used in Arduino. The gateway and node codes do not have to be exclusively those that were made available since the Brazilian identity of the code is in the library itself.

The second step in using LoBRa, as Figure 6.2 shows, is to extract the *loBRa-master* file to the *libraries* folder. It is important that *libraries* are inside *Arduino* and *Documents* so that the IDE (preferably the Arduino IDE) identifies the library and enables the import. At this point, it is important to read the README file, which contains basic information about the constitution of the library.

The next, and last, step is to open through the IDE the code corresponding to the hardware that will be used. The file will prompt to create a subfolder with the same name as the code file. This is because the gateway code and sensor nodes do not have to be in the same directory as the library they use. Finally, it is necessary to select the corresponding hardware, according to Figure 6.3.

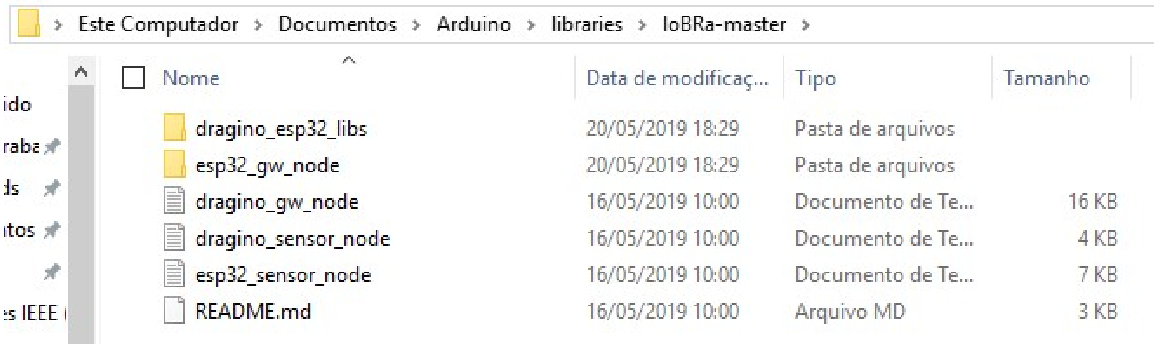


Figure 6.2: Directory indication for correct file extraction.

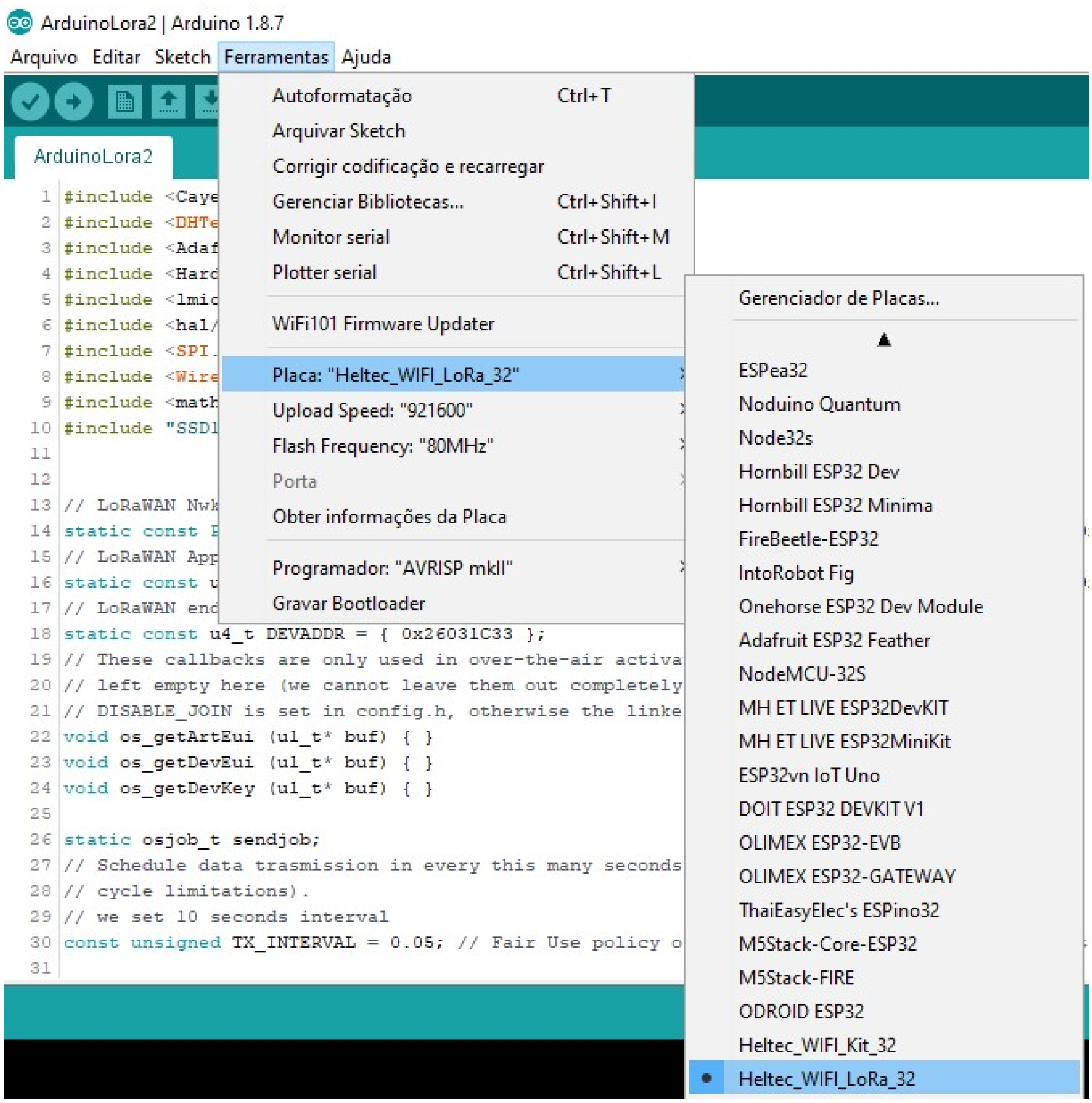


Figure 6.3: Hardware selection by the Arduino IDE.

For the Dragino setup, the Gateway settings are made directly on Raspberry Pi, so no hardware targeting is required for this scenario, as explained in the previous step. After all these steps are performed, the library can be used by the node and gateway codes in the Brazilian scenario, since the settings will already be pre-established.

Also, a personal website for LoRa and LoRaWAN information repository has also been developed, available at ⟨https://sites.google.com/view/lrestivooliveira/home\⟩ (OLIVEIRA, 2019b), with news from the academic community, event information, low-cost prototype development tutorials, hardware instructions and a step-by-step guide on how to use LoBRa. In this step by step, it is shown how to access Github, download all the codes and correctly export the files to the correct directories, since the repository contains not only the Brazilian library but also the gateway and sensor node codes for the different hardware that constituted this project.

The main benefits that the LoBRa library brings are:

- Integration with different versions of LoRa that the LoRa Alliance establishes and maintains in support, since, at the moment, the technological community that holds the property of development and improvement of LoRaWAN is in version 1.1 and has active assistance for version 1.0.
- Adaptive convenience for use with other embedded systems with the same LoRa chip that contains the Dragino and ESP32 LoRa hardware (SX1276/SX1278).
- A clean code, that is, both the code lines developed for Dragino and ESP32 have only what is required for proper operation at 915 MHz, unlike the LMIC code, which covers the entire sub-GHz frequency spectrum and requires configuration and embedded programming knowledge to suit particular needs.
- Material in the Portuguese language, which facilitates a lot for developers unfamiliar with English and enables the scientific advance for beginning researchers. All the tutorials and configuration files are in Portuguese, as well as the support contact and availability of the developed site to facilitate the dissemination of projects at low cost in IoT.
- Expansion of the spectrum of possibilities for the use of embedded hardware, so that those interested in creating innovative solutions can both take advantage of the original LMIC library (lacking improvements in LoRaWAN versions 1.1) and the LoBRa library. It is also a viable issue to integrate between different hardware that each use their respective library but which can interact in a central module and share information.

As future works, it is possible to emphasize that it is necessary to test more hardware and platforms of embedded systems with LoBRa, as well as the LoRa Alliance version 1.1 development check for analysis of improvements and the integration with mobile applications for practicality in the quantification of the sensed data.

Chapter 7

Conclusions and considerations

Although recent, LoRa technology has applications demonstrated in several areas and has as main positive points the reach and consumption of energy, making it a very viable option for IoT, especially in projects that do not require high transmission volume and monitoring in real time applications or in cases where it is not possible to use dedicated infrastructure.

This study was able to understand 3 main topics.

The first one was the identification of a real need in which LoRa would fit to solve activities in IoT, which in this case presented itself as an alternative to Cemaden's communication with rain gauges, for example, since nowadays mobile telephone networks are used and, as presented, it does not have good stability. As a result, it could be seen that a low-cost solution can be created to address both the aspects of transmissions that Cemaden uses and the aspects of alerts for preventive maintenance or remote sensing of external factors that are very aggravating in the problems presented by this type of DCPs, such as the accumulation of dust, leaves or proximity to humans in the vicinity of equipment.

The second topic concerns the validation of LoRa performance with a low cost hardware so that the implementation in scenarios of applications presented by the systematic review can also be used with the prototypes tested in this research project. An important observation in this data collection was that although the tests were done with a temperature sensor, any other type of sensor that is capable of acting on the mentioned variables could also be used, since the transmission protocol would be the same and the format or the size of the message encapsulated by the hardware would also be similar due to the type of technology that all the sensors for Arduino or ESP32 are constituted.

The third can be considered as a social result, in which it can be affirmed that the library in which the tests were validated, LoBRa, which in turn was created and made publicly available, allows the LoRa use scenario in Brazil to be garnished in terms of Anatel specifications and therefore enables new experiments on 915 MHz to SF of 7 to 12 to be performed.

One of the main difficulties encountered in this project was to establish a research laboratory with Cemaden equipment for the integration of tests, which has made it difficult to carry out some field sampling and effective integration with an experimental datalogger. It was also difficult to run tests in harsh environments mainly due to the lack of both support structures for the gateway and the sensor nodes, which would need to be available full time and for long periods in activity. For these reasons, it was possible to create the LoBRa library so that in future works, such a library could be integrated with Cemaden equipment.

With the understanding of this information, the author and contributors were able to have papers approved at a university congress (IV Academic Congress - Unifesp) (OLIVEIRA; CONCEIÇÃO; NETO, 2018a), an specialized magazine in embedded systems (Embarcados.com: Setup LoRa with Arduino, Raspberry Pi and dragino shield) (OLIVEIRA, 2018) and an conference (SBESC - Brazilian Symposium on Computing Systems Engineering) (OLIVEIRA; CONCEIÇÃO; NETO, 2018b). Besides, a study of the main applications of LoRa has been submitted to ACM Computing Surveys and is currently being analyzed.

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Appendix A

Sensor node code - Dragino

Identification of the encryption keys used.

```
{...}
static const PROGMEM u1_t NWKSKEY[16] = { 0xA3, 0xFB, 0xB7, 0x18, 0xA9, 0
    ↪ xCB, 0x4E, 0xB1, 0x2A, 0x3C, 0xEE, 0x54, 0xBA, 0xF8, 0xF2, 0xD9 };
static const u1_t PROGMEM APPSKEY[16] = { 0xAE, 0x41, 0xF3, 0x1B, 0x03, 0
    ↪ x3C, 0x53, 0x0D, 0x94, 0x22, 0xA8, 0xE0, 0x89, 0xD1, 0xB4, 0x79 };
static const u4_t DEVADDR = 0x26031433;
{...}
```

Mapping the communication pins.

```
{...}
const lmic_pinmap lmic_pins = {
  .nss = 10,
  .rxtx = LMIC_UNUSED_PIN,
  .rst = 9 ,
  .dio = {2, 6, 7},
};
{...}
```

Definition of baud rate and initialization.

```
{...}
Serial.begin(9600);
analogReference(INTERNAL);
while (!Serial);
Serial.println("Starting");
```

```
{...}
```

Selecting the spreading factor and disabling inactive channels.

```
{...}
os_init();
LMIC_reset();
#ifdef PROGMEM
uint8_t appskey[sizeof(APPSKEY)];
uint8_t nwkskey[sizeof(NWKSKEY)];
memcpy_P(appskey, APPSKEY, sizeof(APPSKEY));
memcpy_P(nwkskey, NWKSKEY, sizeof(NWKSKEY));
LMIC_setSession (0x1, DEVADDR, nwkskey, appskey);
#else
LMIC_setSession (0x1, DEVADDR, NWKSKEY, APPSKEY);
#endif
LMIC_setLinkCheckMode(0);
LMIC.dn2Dr = DR_SF9;
LMIC_setDrTxpow(DR_SF10, 14);
for (int i = 1; i &lt; 64; i++) {
  LMIC_disableChannel(i); // only the first channel 902.3Mhz works now.
}
do_send(&amp;sendjob);
{...}
```

Analog signal conversion made by Arduino.

```
{...}
void loop() {
os_runloop_once();
temp_lida = analogRead(LM35);
temperatura = temp_lida * 0.1075268817204301;
}
{...}
```

Appendix B

Gateway code - Dragino

Pinout of RPi, SF and frequency of operation.

```
{...}
enum sf_t { SF7=7, SF8, SF9, SF10, SF11, SF12 };

int ssPin = 6;
int dio0 = 7;
int RST = 0;

sf_t sf = SF7;

uint32_t freq = 915000000;
{...}
```

Pointing a TTN server.

```
{...}
#define SERVER1 "13.76.168.68"
#define PORT 1700
{...}
```

Appendix C

Sensor node code - ESP32 LoRa Heltec

Mapping the communication pins.

```
{...}
const lmic_pinmap lmic_pins = {
  .nss = 18,
  .rxtx = LMIC_UNUSED_PIN,
  .rst = 14,
  .dio = {26, 33, 32},
};
{...}
```

Definition of baud rate and sensor initialization.

```
{...}
Serial.begin(115200);
gpsSerial.begin(115200, SERIAL_8N1, SERIAL1_RXPIN, SERIAL1_TXPIN);
Serial.printf("Starting...\r\n");

pinMode(16,OUTPUT);
digitalWrite(16, LOW); // set GPIO16 low to reset OLED
delay(50);
digitalWrite(16, HIGH);
display.init();
display.setFont(ArialMT_Plain_10);

dht.setup(dhtPin, DHTesp::DHT11);
{...}
```

Selection of spreading factor.

```
{...}
os_init();
LMIC_reset();
uint8_t appskey[sizeof(APPSKEY)];
uint8_t nwkskey[sizeof(NWKSKEY)];
memcpy_P(appskey, APPSKEY, sizeof(APPSKEY));
memcpy_P(nwkskey, NWKSKEY, sizeof(NWKSKEY));
LMIC_setSession (0x1, DEVADDR, nwkskey, appskey);
LMIC_selectSubBand(0);
LMIC_setLinkCheckMode(0);
LMIC.dn2Dr = DR_SF9;
Serial.printf("Biblioteca␣pronta!\r\n");
do_send(&sendjob);
{...}
```

Appendix D

Gateway code - ESP32 LoRa Heltec

Wifi settings.

```
{...}
struct wpas {
       char login[32];
       char passw[64];
};
wpas wpa[] = {
   { "login", "passw" }
};
{...}
```

Definition of frequency plane and spreading factor structure.

```
{...}
int freqs [] = {
  902300000,
  903000000,
  915000000,
};
uint32_t freq = freqs[2];
uint8_t ifreq = 0;
enum sf_t { SF7=7, SF8, SF9, SF10, SF11, SF12 };
{...}
```

Gateway address setting.

```
{...}
```

```
#define _DESCRIPTION "LoRa␣ESP32␣Unifesp"
#define _EMAIL "l.restivo93@gmail.com"
#define _PLATFORM "ESP32LoRa"
#define _LAT -23.223701
#define _LON -45.9009074
#define _ALT 599
{...}
```

Appendix E

LoBRa

Definitions of the full spectrum of SF for 915 MHz in lorabase.h.

```
{...}
enum _dr_us915_t { DR_SF12=0, DR_SF11, DR_SF10, DR_SF9, DR_SF8, DR_SF7,
   ↪ DR_SF8C, DR_NONE,
                  DR_SF12CR=8, DR_SF11CR, DR_SF10CR, DR_SF9CR, DR_SF8CR,
                     ↪ DR_SF7CR };
enum { DR_DFLTMIN = DR_SF8C };
enum { DR_PAGE = DR_PAGE_US915 };
{...}
```

Addressing the full spectrum of SF to 915 MHz in lorabase.h with coding rate.

```
{...}
    MCMD_LADR_SF12 = DR_SF12<<4,
    MCMD_LADR_SF11 = DR_SF11<<4,
    MCMD_LADR_SF10 = DR_SF10<<4,
    MCMD_LADR_SF9 = DR_SF9 <<4,
    MCMD_LADR_SF8 = DR_SF8 <<4,
    MCMD_LADR_SF7 = DR_SF7 <<4,
    MCMD_LADR_SF8C = DR_SF8C<<4,
    MCMD_LADR_SF12CR = DR_SF12CR<<4,
    MCMD_LADR_SF11CR = DR_SF11CR<<4,
    MCMD_LADR_SF10CR = DR_SF10CR<<4,
    MCMD_LADR_SF9CR = DR_SF9CR<<4,
    MCMD_LADR_SF8CR = DR_SF8CR<<4,
    MCMD_LADR_SF7CR = DR_SF7CR<<4,
```

```
{...}
```

Definitions in limc.c for the entire SF spectrum at 915 MHz.

```
{...}
#define dr2hsym(dr) (TABLE_GET_OSTIME(DR2HSYM_osticks, (dr)&7)) // map
    ↪ DR_SFnCR -> 0-6
    us2osticksRound(128<<7), // DR_SF12 DR_SF12CR
    us2osticksRound(128<<6), // DR_SF11 DR_SF11CR
    us2osticksRound(128<<5), // DR_SF10 DR_SF12CR
    us2osticksRound(128<<4), // DR_SF9 DR_SF11CR
    us2osticksRound(128<<3), // DR_SF8 DR_SF10CR
    us2osticksRound(128<<2), // DR_SF7 DR_SF9CR
    us2osticksRound(128<<1), // DR_SF8C DR_SF8CR
    us2osticksRound(128<<0) // ------ DR_SF7CR
{...}
```

Constant tables in lmic.c for operation on all SF spectrum at 915 MHz.

```
{...}
CONST_TABLE(u1_t, maxFrameLens) [] = { 24,66,142,255,255,255,255,255,
    ↪ 66,142 };

CONST_TABLE(u1_t, _DR2RPS_CRC)[] = {
    ILLEGAL_RPS,
        MAKERPS(SF12, BW125, CR_4_5, 0, 0),
    MAKERPS(SF11, BW125, CR_4_5, 0, 0),
    MAKERPS(SF10, BW125, CR_4_5, 0, 0),
    MAKERPS(SF9, BW125, CR_4_5, 0, 0),
    MAKERPS(SF8, BW125, CR_4_5, 0, 0),
    MAKERPS(SF7, BW125, CR_4_5, 0, 0),
    MAKERPS(SF8, BW500, CR_4_5, 0, 0),
    ILLEGAL_RPS,
    ILLEGAL_RPS,
    ILLEGAL_RPS,
    MAKERPS(SF12, BW500, CR_4_5, 0, 0),
    MAKERPS(SF11, BW500, CR_4_5, 0, 0),
```

```
    MAKERPS(SF10, BW500, CR_4_5, 0, 0),
    MAKERPS(SF9, BW500, CR_4_5, 0, 0),
    MAKERPS(SF8, BW500, CR_4_5, 0, 0),
    MAKERPS(SF7, BW500, CR_4_5, 0, 0),
    ILLEGAL_RPS
};
{...}
```

Variations in bandwidth in lmic.c for operation in all SF spectrum at 915 MHz.

```
{...}
static CONST_TABLE(u1_t, SENSITIVITY)[7][3] = {
    // ------------bw----------
    // 125kHz 250kHz 500kHz
    { 141-109, 141-109, 141-109 }, // FSK
    { 141-127, 141-124, 141-121 }, // SF7
    { 141-129, 141-126, 141-123 }, // SF8
    { 141-132, 141-129, 141-126 }, // SF9
    { 141-135, 141-132, 141-129 }, // SF10
    { 141-138, 141-135, 141-132 }, // SF11
    { 141-141, 141-138, 141-135 } // SF12
};
{...}
```

Adaptation of the chip in radio.c to accept in different bands.

```
{...}
#ifdef CFG_sx1276_radio
        u1_t mc1 = 0, mc2 = 0, mc3 = 0;

        switch (getBw(LMIC.rps)) {
        case BW125: mc1 |= SX1276_MC1_BW_125; break;
        case BW250: mc1 |= SX1276_MC1_BW_250; break;
        case BW500: mc1 |= SX1276_MC1_BW_500; break;
        //default:
          // ASSERT(0);
        }
```

```
{...}
```

The complete code can be consulted in Github at ⟨https://github.com/LucasRestivo/LoBRa⟩ (OLIVEIRA, 2019a)).

Appendix F

Gateway configuration

After all the connections between the Dragino and the RPi, the programming of the RPi via the terminal command line was performed.

The first task was to clone the software directory that the gateway will execute, according to Figure F.1.

```
git clone https://github.com/tftelkamp/single_chan_pkt_fwd
```

Figure F.1: Command for directory clone.

Then, since serial synchronous communication between the hardware is required, the Serial Peripheral Interface (SPI) is enabled and the RPi is restarted, as shown in Figures F.2 and F.3.

```
pi@raspberrypi:~ $ sudo raspi-config
```

Figure F.2: RPi Configuration.

The SPI interface requires confirmation to enable and is sequenced from a reset on the platform, according to Figure F.4. Also, in order to control the GPIO pins of the RPi it is necessary to execute the command of Figure F.5. These commands are required because the communication between the different types of electronic components has different internal compositions, which means that without a common interface capable of executing all the hardware demands, it would not be possible to validate the LoRa transmission.

In the main file that was cloned, some adjustments had to be made to better fit the Brazilian scenario. Thus, the main source file was accessed and then changed according to Figure F.6.

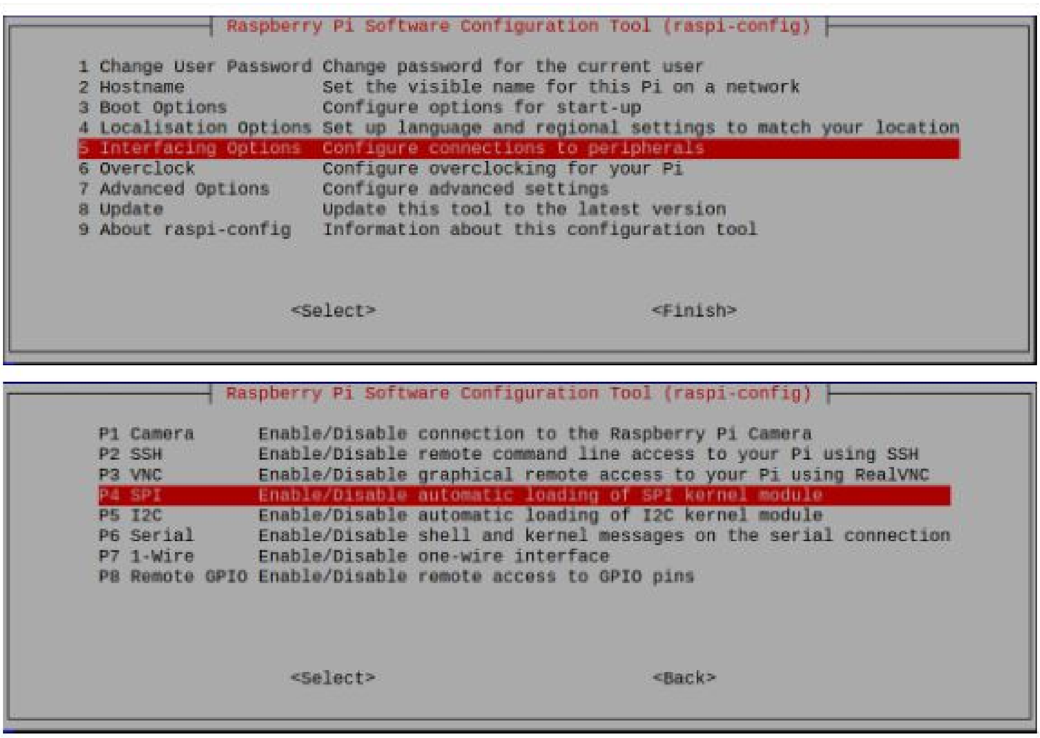

Figure F.3: SPI Configuration.

Figure F.4: RPi Reset.

Figure F.5: RPi Wiring.

Figure F.6: Command for basic configuration changes.

The settings that need to be made are the spreading factor, which ranges from 7 to 12 (with limitations from 7 to 10 to 915 MHz due to dwell time) and the frequency of operation. By default, the transducer enable pins are already cloned with the correct definitions for use in the RPi, and therefore, the sequence for ssPIn, dio0, and RST remained at 6, 7 and 0, as shown in Figure F.7.

The geographical location of the gateway can also be parameterized in this step, according to Figure F.8.

Afterwards, a server and a valid port for connecting the RPi to the network were directed. This server varies according to the cloned main file, and Dragino itself establishes

```
// SX1272 - Raspberry connections
int ssPin = 6;
int dio0  = 7;
int RST   = 0;

// Set spreading factor (SF7 - SF12)
sf_t sf = SF10;

// Set center frequency
uint32_t  freq = 915000000; // in Mhz! (915.0)
```

Figure F.7: Base Settings.

```
// Set location
float lat=-22.89253001;
float lon=-46.407123430;
int   alt=350;
```

Figure F.8: Gateway location settings.

some available servers, although they depend on momentary availability.

```
// define servers
// TODO: use host names and dns
#define SERVER1 "13.76.168.68"
//#define SERVER2 "192.168.1.10"
#define PORT 1700
```

Figure F.9: Server pointer to the gateway.

Finally, if any modifications have been made to the main file, the F.10 command should be performed to run the software and update all new settings.

```
pi@raspberrypi:~/single_chan_pkt_fwd $ make
```

Figure F.10: Updating gateway settings.

If everything is configured according to the characteristics of the hardware used, when running the program, the gateway will be able to receive packets from whatever node it is sending, as well as showing the operating frequency that it is working and the spreading factor. Other information such as the gateway identifier address and packet receive data can also be queried by the RPi, although the information is best viewed on the cloud server that the system will interact with.

```
pi@raspberrypi:~/single_chan_pkt_fwd $ ./single_chan_pkt_fwd
SX1276 detected, starting.
Gateway ID: b8:27:eb:ff:ff:33:fa:b6
Listening at SF10 on 915.000000 Mhz.
------------------
stat update: {"stat":{"time":"2018-02-07 17:39:26 GMT","lati":-22.89253,"long":-46.40712,"alti":3
50,"rxnb":0,"rxok":0,"rxfw":0,"ackr":0.0,"dwnb":0,"txnb":0,"pfrm":"Single Channel Gateway","mail"
:"","desc":""}}
```

Figure F.11: Gateway configured and ready.

Appendix G

Sensor node configuration

Regarding the connection of the Dragino to the Arduino, it was enough to carefully connect the shield so that all the pins were connected in the respective spots, after, the USB cable should be plugged into the Arduino and connected to the computer so that programming can be performed by the development interface. To test the remote sensing tests with the LoRa, the temperature sensor LM35 was inserted, powered with 5V and programmed by the analog pin 0 of the Dragino. The scatter factor settings on the sensor node have been adjusted in the same way as for the gateway.

Some important lines of code used for the sensor node can be checked in Appendix A, but some observations must be taken into account for the sensor node:

- In the source code, the LM35 was set as an example point for measuring the temperature, however any other type of sensor whose captured information is of low bit rate could also be used.

- The channel limitation, however, was made so that the sensor node only channels the obtained data and transmits in a single frequency.

```
for (int i = 1; i < 64; i++) {
    LMIC_disableChannel(i);
}
```

- The library used is the LMIC and in the subdirectories of this library, the config.h file was changed to the Brazilian standardization.

```
// #define CFG_eu868 1
#define CFG_us915 1
```

- In the lorabase.h file, the correct operating frequency also had to be adjusted.

```
// Default frequency plan for US 915MHz
enum { US915_125kHz_UPFBASE = 915000000,
```

- In line 760 of the file *limic.c* the channel division for future uses should be adjusted. Limitation on the number of transmission channels was performed since there are not many uplinks or downlinks, which means that for the simple remote sensing of a node, a channel is sufficient to check the environmental conditions and send to a gateway connected to the cloud. Therefore, it was necessary to disable all channels that would not be in use since if this were not done, the transmitter would try to send packets on all existing channels while the receiver would only be able to operate on a channel.

```
void LMIC_disableChannel (u1_t channel) {
    if( channel < 72+MAX_XCHANNELS )
        LMIC.channelMap[channel>>16] &= ~(1<<(channel&0xF));
}
```